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—Craig E. Dorman
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Director's Statement

We are often asked about the Woods Hole Oceanographic Institution's position on environmental issues, including the complex topic of waste management. As a research and education center, dedicated to the highest standards of scientific and technical excellence, our duty is to foster the pursuit of objective research and education, not to endorse a particular position. We strive to ensure that the work of science is conducted in an open environment, where ideas, no matter how unconventional, can flow freely and be openly debated.

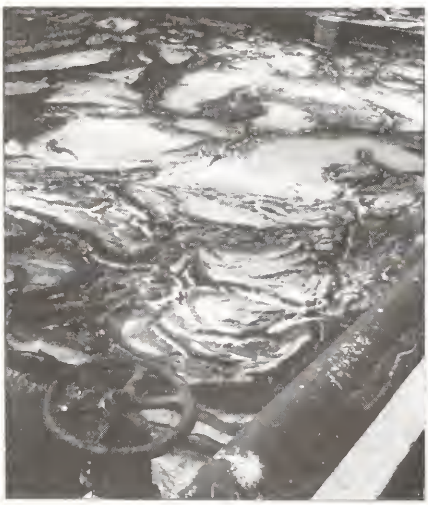
This issue of *Oceanus* speaks to only a small portion of the waste management issue—whether the ocean can safely play a role in some kind of waste disposal. All the opinions expressed in the following articles and editorials are those of the individual authors and not necessarily those of the Woods Hole Oceanographic Institution. We hope these articles will extend and enhance a debate that is too often driven by emotion rather than fact.

—Craig E. Dorman
Director, Woods Hole Oceanographic Institution

OCEAN DISPOSAL RECONSIDERED

The influence of effluents

Incineration and other options



Whither the sludge?

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Headings and Readings

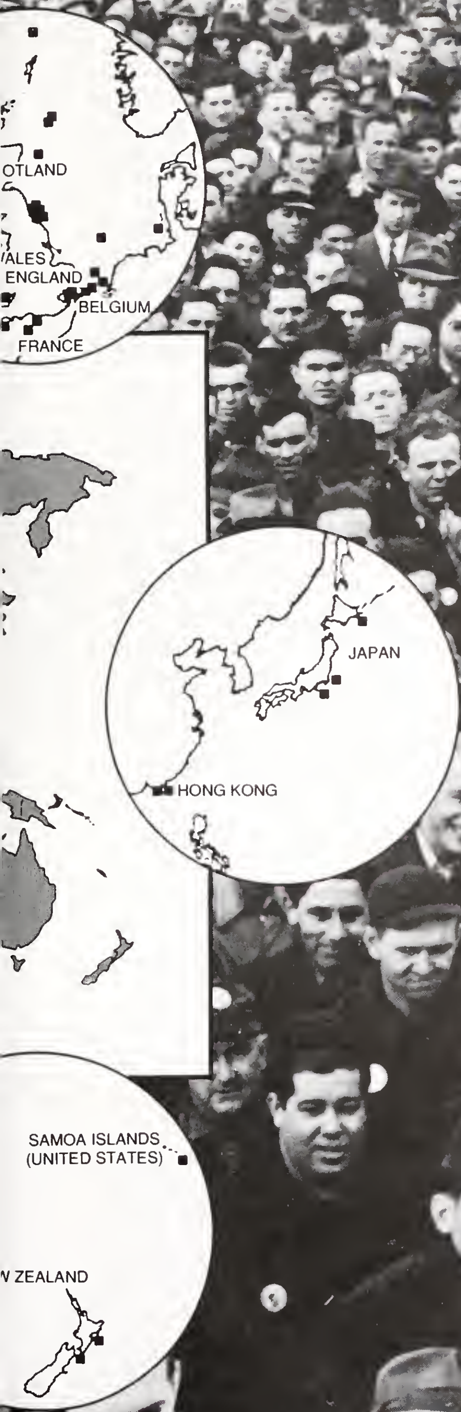
Coastal concerns

Cartoonists' views

Poet-Oceanographer

COVER: Robert Mankoff is an editorial cartoonist whose work has appeared in *The New Yorker*, most recently on April 23, 1990, with a cover celebrating Earth Day. Other credits appear on page 86.

Ocean disposal sites around the world, according to 1985 statistics of the London Dumping Convention.



Introduction

The Ocean and Waste Management

by Derek W. Spencer

In this issue, we examine several aspects of waste disposal in the ocean—its history, effects, and future. More importantly, we ask whether the ocean may have a legitimate role in optimal waste-management practices in the future.

The disposal of waste materials is one of the most critical problems facing our nation and the world. The burgeoning world population and the associated increase in resource utilization is creating a waste stream of gigantic proportions and highly variable content. Present waste-management practices are insufficient to handle today's problems, yet further population growth is inevitable.

The sheer volume of wastes, or the "waste stream," together with threats to precious ground water supplies and problems with noise and odor pollution, have combined to make landfill disposal sites a rapidly diminishing resource. Such sites now handle more than 80 percent of the U.S. waste stream. We

urgently need innovative and effective solutions for dealing with wastes.

Human activities generate both unused and unusable products of some kind. Historically, this material was destroyed by burning or, more often, discarded in some place out of sight and mind. From the dawn of civilization through the birth of the Industrial Revolution, when the Earth's population was less than a billion and the use of resources was small, such practices were often sufficient and caused little detriment to the quality of human life. However, this was not always the case as is evident by the inadequate treatment of refuse that led, in medieval times, to explosions of rat populations and the spread of bubonic plague.

The United States annually disposes of an estimated 1.3 billion tonnes of waste.

Since the early 1800s, technological advances in disease control and expanded food sources have engendered enormous growth of the world's population, from somewhat less than a billion in 1800 to about 5.2 billion today, and projected to 6.5 to 7 billion by the year 2000. This huge and continuing population growth, together with increasing demands and expectations concerning quality of life, is bringing great stress on our environment because of the high volume of resources we use and the wastes we discard. Of the 5.2 billion people who now inhabit Earth, more than 40 percent are under 15 years old. Thus, the stage is set for a continued mushrooming of the world's population, and the concomitant growth of resource use and the waste stream.

It is difficult to obtain global data illustrating the extent of the waste-management problem, but data from the United States—which also has experienced great population growth—serve as indicators. Annually, the United States disposes of an estimated 1.3 billion tonnes of wastes that fall, broadly, into the following categories:

	Millions of Tonnes	Percent
Municipal Solid Waste (MSW)	180	14.1
Sewage Sludge (wet)	300	23.4
Dredged Materials	400	31.3
Industrial Waste (wet and solid)	400	31.3

How much waste is 1.3 billion tonnes? If it were all loaded into 10-ton trucks, and we lined up the trucks bumper-to-bumper, the convoy would stretch around the Earth more than 20 times. The garbage and trash (MSW) convoy, the smallest of the above categories, would circle the globe almost three times, and it is growing. But what happens to this garbage and trash now? Because of aesthetic problems associated with "floatables," no U.S. municipalities now dump garbage into the ocean and have not done so since 1934. About 80 percent is landfilled in some 6,500 facilities, about 10 percent is burned in 155 large, modern incinerators, and about 10 percent is recycled. Can this continue?

More than 2,000 of the nation's 6,500 landfills will close within five years. This means a loss of capacity of 51 million tonnes a year. New landfill construction will provide a capacity of only about 18 million tonnes a year. Because of noise pollution problems, odor, and hazards associated with groundwater contamination, we are running out of land to devote to waste containment. Some 29 new incineration plants are under construction, but a further 64 have been held up by litigation. Burning may seem an answer, but incineration reduces garbage to about only 25 percent of its initial mass. Disposal of the residual toxic ash also is a management problem.

Landfills, such as New York City's Freshkills—the world's largest—are a vanishing breed.

Many heavily urbanized states export their garbage. New Jersey, for example, now exports more than 55 percent of its MSW, mostly to other states, but some to foreign countries. The number of states and countries that will accept this load is steadily and rapidly declining.

Jerry Schubel of the State University of New York at Stony Brook, in an address to the Marine Board of the National Academy of Sciences, has succinctly encapsulated the management problems of MSW with his statement—"There is too much of it, it is too persistent, it is too 'toxic,' and we have too few places on land to put it."

Much of MSW is, in fact, reducible or reusable. There are now some enlightened manufacturers who have found substantial economies in reducing excessive packaging or have taken advantage of products that are recyclable and/or biodegradable. A great deal more effort must be expended in source reduction and in recycling. Some states, towns, and municipalities have adopted mandatory recycling—more will have to do so.

However, as the article by Iver Duedall points out (see page 29), municipal solid wastes are just part of the problem. The large volumes of dredge spoils, which after 1991 will be the only solid material that may be legally deposited in the marine environment, pose some problems as outlined by Robert Engler (see page 63). However, the management of sewage sludge and industrial wastes poses the greatest problems. With the latter, in particular, there are some extremely hazardous products, including highly toxic chemicals and radioactive materials.

The U.S. Environmental Protection Agency (EPA) has set a national goal of 25 percent for reduction and recycling by 1992. Even if this can be met, there will still be much more waste than can

be accommodated by land-based disposal systems now at hand, or planned for the immediate future. The options for this excess are limited: we can put it in the air, the ocean, or subsea sediments. While some believe that space may be an option, technology and economic factors clearly obviate this possibility.

All waste-disposal options pose similar environmental concerns. Risks to human health, loss of valuable resources, and environmental degradation are common to all disposal alternatives, whether land-based, aquatic, or atmospheric. The transport, fate, and effects of wastes discharged to any environment are dependent on physical, chemical, and biological processes that control contaminants within that environment.

Options for excess waste are limited: air, ocean, or subseabed sediments.

Today, our disposal-management practices do not address the broadly based nature of the above-mentioned risks. In the last 20 years, legislation concerning environmental issues was passed as a result of crisis management. Laws were enacted on a piecemeal basis following the detection of pollution in freshwater and marine environments, in air, or on land.

In response to these laws, a maze of overlapping regulations were developed, all attempting to impose control at the point of contaminant introduction to the environment.

Our failure to deal adequately with waste-management issues is well illustrated by the recent concern over ocean dumping. The public outcry during the spring and summer of 1988, coupled with unusual environmental events (for example, mass mortalities of marine mammals, medical wastes on beaches, disease in commercial fisheries, and so on), again led to congressional action for the cessation of dumping sludge and industrial waste in the ocean by the end of 1991.

Environmentalists, fishermen, and businessmen aligned with coastal tourism praised this action as tough environmental legislation protecting our coastal waters. Yet, the causal links between ocean dumping and the observed environmental events of the summer of 1988 have not been defined and, in many instances, there is no relationship whatsoever.

The contribution from Judith McDowell Capuzzo (see page 39) indicates that the input of chemical contaminants from ocean dumping is only a small proportion of the total chemical contaminant burden to coastal environments. Untreated sewage effluents, land-based runoff, industrial effluents, and dredged materials are quantitatively more important sources of persistent chemical contaminants, such as chlorinated hydrocarbons and polynuclear aromatic hydrocarbons (see page 54), than is sewage sludge.

Cessation of ocean dumping will not reverse the increasing trends in coastal degradation that have become more widespread despite the perceived progressive action in environmental

Plowing through the sludge: Americans dispose of 300 million tonnes of sewage sludge each year.

legislation. It is vitally important that we recognize the many sources of marine pollution and install programs that can effectively solve the problems.

There is now wide recognition that inadequate waste control and management has contributed to our social problems as a nation and as citizens of the world. Present problems will be magnified greatly in the future unless some bold, and effective, new approaches are introduced. Many who have considered the issues advocate what is essentially a two-step approach:

- *Conservation: waste reduction by source reduction and recycling.*
- *Multimedia disposal: to minimize risks.*

Increased efforts in conservation will be essential. Programs such as the 3P program (Pollution Prevention Pays) developed by the 3M Company must be adopted by more industries. Michael A. Champ and Paul Kilho Park (see page 77) have indicated elsewhere that the 3P program reduces waste by product reformulation, process modification, equipment redesign, recovery of wastes for reuse, and reduction of packaging. The program has led to reduced costs, improved technologies and products, conservation of resources, and improved public and environmental health.

Champ and Park also point out that the Clean Japan Center has developed extensive and effective programs for recycling and resource recovery from wastes. State and local recycling programs are now emerging and more must come. However, conservation, at best, can reduce, but not eliminate, the problem. Wastes, in quantities requiring well-considered disposal strategies, will remain.

We must design optimal waste-management programs that minimize risks to human health and the environment. In the United States, present legislation does not allow the implementation, or even consideration, of optimal practices. In particular, the

Tokyo survived Godzilla, but the plastic trash now eating up Tokyo Bay has the Japanese scrambling to cut plastic use.

"ocean option" has been almost discarded. As the contribution by Champ illustrates (see page 45), this state of affairs has arisen largely out of public concern for a healthful coastal environment and a lack of public awareness of what the major sources of chronic pollution in the coastal ocean are, and what the ocean, in its totality, is really like.

Ideally, waste-management strategies should consider all options and include safety, scientific information, available or needed technology, and economic factors. In reality, as Thomas R. Kitsos of the U.S. House of Representatives Merchant Marine and Fisheries Committee, and others, have stated ". . . waste disposal decisions most often occur in response to discrete issues, the factual and perceptual bases of which change constantly as technical information and public awareness expand." Politics has played, and will continue to play, a dominant role. Political strategies for productive cooperation among countries, states, municipalities, and industrial organizations must be an integral part of waste-management programs. Kitsos and Joan Bondareff review the development of current policies on ocean waste disposal (see page 23).

Politics has played, and will continue to play, a dominant role in waste-management programs.

Many ocean scientists and engineers are concerned that options that could minimize the risks associated with the disposal of many waste materials are now spurned because of current law and public misunderstanding.

More than 70 percent of the Earth's surface is covered by the ocean and, although we do not inhabit the ocean, it is essential to our welfare. The ocean's ability to store and transport heat from the sun controls and moderates our weather and climate. We reap many resources from the ocean, including food and minerals. The ocean coastal environment is a major recreational resource in almost every country. It is a resource we cannot afford to lose by careless, indiscriminate acts.

The coastal boundary is only a small fraction of the total volume of the ocean. However, it is the area of principal interaction with man and, as indicated by McDowell Capuzzo, it is an extremely productive region. Of all the ocean regions, the coastal zone receives the predominant impact of human activities, from rivers and the continental atmosphere to direct utilization for industrial and recreational purposes.

The coastal regions supply most of the resources that are currently harvested from the sea, principally fish, sand, gravel, oil, and gas. However, the scope of coastal regions contrasts markedly with the rest of the ocean. The vast, deep, abyssal hills and plains of the mid-latitude regions of the Atlantic and Pacific oceans are deserts. Life is sparse and mineral wealth almost nonexistent.

Our understanding of the many and varied regimes enclosed by ocean basins has increased enormously in the last 30 years. We

know the major processes that drive water motion. We know how and where the water-masses originate. We know the major processes that transport materials in the ocean and we have substantial information on the rates at which these processes operate. We know that, while the ocean mixes laterally on time-scales of days to months, it mixes vertically on much longer time scales, up to thousands of years. We know the composition of virtually all marine sediments and the rates at which they accumulate.

Charles Hollister points out (see page 13) that we know where there are vast areas of quiescent, stable ocean bottom with oozes hundreds of feet thick that have accumulated slowly and steadily for millions of years. We know, too, of other areas that are stirred and mixed by major "benthic storms." We know a great deal about the life that inhabits many ocean regions, what is required for its sustenance, and what may be devastating to its existence. In short, we now have the knowledge to assess which ocean environments may be suitable, or unsuitable, repositories for many wastes.

Our present understanding of the probability of impact to man from the use of these sites leads us to believe that they may, in many instances, provide reduced risk and more optimal opportunities for future waste-management plans. Studies at such organizations as the Woods Hole Oceanographic Institution have shown us that, in general, the ocean is quite robust and that internal feedback processes resist and ameliorate change particularly when perturbations are at a rate that is consistent with the ocean's capacity to assimilate.

The concept of the "fragile ocean" arises in regions where human activities exceed the capacity of the ocean to absorb wastes.

The concept of the "fragile ocean" arises in regions where human activities have exceeded the capacity of the ocean to absorb wastes. These are mostly in coastal sites associated with major metropolitan areas, such as Boston Harbor and the New York Bight. In such coastal regions, the total contaminant burden derives from many sources. Sewage effluents, land-based runoff, industrial effluents, atmospheric inputs, disposal of dredged materials, and sewage sludge all contribute to the overburdened ocean. In the future, while carefully controlled and monitored releases to coastal regions may be considered, it is the *deep ocean* that offers the greatest potential for low-risk waste-management options.

Although we can point to the potential of regions of the deep ocean as a waste repository, there is still much to learn about the interaction of wastes and the marine environment. Perhaps the most troubling aspect of the present legislative regime is that no government agency is presently charged with the responsibility to explore the ocean option. No funding is available for research on the environmental effects of ocean waste disposal, or on the technology for waste emplacement and monitoring.

"I don't know why I don't care about the bottom of the ocean, but I don't."

With the mounting volumes of waste, pressures for ocean utilization will increase. One can imagine the dear lady who doesn't care about the bottom of the ocean (see *New Yorker Magazine* cartoon above) standing outside her stately mansion with a mountain of garbage encroaching on her backyard, saying: "Now I know why I should care about the bottom of the ocean."

Derek W. Spencer is a Senior Scientist in the Chemistry Department of the Woods Hole Oceanographic Institution. Until recently, he was the Associate Director for Research, a position he held for many years.

Editorial

Options for Waste: Space, Land, or Sea?

by Charles D. Hollister

In the remote settlements of the Himalayas, villagers would not throw away a tin can, because a tin can is useful. They can cook in it, drink from it, put their prayer beads in it. Little trash is generated in those mountain villages. Our industrialized societies, however, produce vast quantities of waste, some of which is hazardous. We have so much hazardous waste, that if we put all of it in tractor-trailers, the trucks would stretch one-and-a-half times around the globe at the equator (51,500 kilometers).

Waste is an unavoidable result of human activity: the more humans, the more waste. Efforts to deal with our prolific waste output have proven so dismally ineffectual and uncoordinated that it is not entirely ridiculous to suggest family planning as a future waste-management option.

We must minimize the amount of waste we generate, produce "cleaner" waste, and recycle or reuse as much waste as possible. We are far from achieving these ends, but even if we did, we still would have a waste problem. Not all waste can be recycled or treated, and treatment itself produces waste. For instance, incin-

eration destroys the hazardous constituents in certain materials, but incineration pollutes the air and the leftover ash is usually toxic. Chemical neutralization—putting a buffer into acidic waste—can reduce toxicity, but the end result is still waste.

No matter how much we recycle, no matter how clean-burning our industries become, the terrible truth is that by the end of the day, we will be left with waste. This waste is not going to disappear, ever, no matter how fervently we scream: "Not in my term of office!" (NIMTOO) and "Not in my backyard!" (NIMBY). We have only four backyards: space, air, land and sea.

Shooting Waste Into Space

Shooting waste out of Earth orbit might sound attractive, but it is the most problematic option of all. For high-volume waste, such as garbage, we could not afford to make enough rockets. And the production of a rocket itself produces large quantities of toxic waste.

Neither are rockets feasible for even small-volume, high-level radioactive waste, which contains plutonium. To get rid of this kind of waste, that is, the amount on hand by the year 2000, we would have to guarantee liftoff of 1,000 Saturn-V rockets. And the high-level nuclear waste we continue to generate would require a Saturn-V takeoff about once a week, forever. We also would have to guarantee no Challenger-type disaster because vaporized plutonium is one of the deadliest substances known.

Land Disposal

Land covers 29 percent of the planet. If we exclude communities, national parkland, and areas underlain by groundwater, we are left with mostly mountain and desert regions. These areas represent about 5 percent of the planet's total land area—available, theoretically anyway, for waste disposal.

Land disposal is our government's backyard of choice for all wastes. The most serious disadvantage of land disposal is the potential for endangering drinking-water supplies. Recently, strengthened laws limit the options for land disposal, and public opposition has made siting new landfills difficult, if not impossible. The U.S. Environmental Protection Agency estimates that within 20 years, 80 percent of all existing landfills will be closed.

The Ocean

Our only other backyard, the ocean, covers 71 percent of the Earth. We have dumped all kinds of waste into the seas. However, we have grown increasingly uncertain about whether the ocean is the place for wastes. In fact, the U.S. Congress enacted legislation that prohibits putting industrial waste and sewage sludge in the ocean after December 31, 1991. We should and must

protect the seas, but as science progresses and we learn more about the ocean, these laws may be amended. If the colossal waste-disposal problem continues to remain unresolved, we have an obligation to reconsider the ocean's possible role in waste management.

The ocean is a prime dilutor and buffer: seawater dilutes material and ocean currents spread it around. Could ocean dilution be an acceptable way of lessening or eliminating the toxicity of certain waste that cannot be recycled or reused? Much more research is necessary before we can give ocean dilution the nod, but there are possibilities that merit scrutiny—such as the blizzard-like storms that occur in the deep sea.

> A Wall Poster Seen at EPA*
>
> ## *The ABCs of Waste Disposal*
>
> ***NIMBY...Not In My Back Yard***
> ***NIMFYE...Not In My Front Yard Either***
> ***PIITBY...Put It In Their Back Yard***
> ***NIMEY...Not In My Election Year***
> ***NIMTOO...Not In My Term Of Office***
> ***LULU...Locally Unavailable Land Use***
> ***NOPE...Not On Planet Earth***
>
> *Environmental Protection Agency

In the early 1980s, my colleagues and I discovered episodic currents in the deep sea strong enough to lift sediment from the seafloor. By deep-sea standards, these are extremely fast and powerful.

These currents, dubbed "benthic storms," stir up the bottom, pick up mud, and distribute it downstream onto kilometer-high mud mounds more than 300 kilometers across. The biggest supertanker full of sewage sludge would hold a thousandth of the total load of mud carried by a single benthic storm. We have directly recorded benthic storms, about six a year, in the western North and South Atlantic. Benthic storms probably occur elsewhere in the global ocean as well.

What would happen if waste were introduced into the center of a stormy region at a depth of about four kilometers? We really don't know; we need more research and experimentation. But we think we can predict where particulate waste is likely to go because we have determined where the mud picked up by the current eventually goes. The mud is laid downstream on the mountainous piles as a miniscule addition to the millions of cubic meters of mud that have been collecting there for millions of years.

Even if this idea proved feasible for certain kinds of high-volume, mildly toxic waste, it probably would not work for low-

volume, very toxic, heavy metals and radioactive materials—substances we really do not want dispersed in the ocean. But for these types of waste, the ocean may offer another alternative based on containment.

Mud Like Peanut Butter

One vast region of the central North Pacific might be a safe place to bury wastes in the deep subseabed.

About half the Earth is covered by vast underwater fields of clayey mud resembling creamy peanut butter. Miles thick, these muds carpet vast areas of deep-sea basins and certain areas of the U.S. Exclusive Economic Zone, which extends to 200 nautical miles from our coasts. The particles of this oceanic peanut butter are so fine-grained that they are measured in thousandths of a millimeter—the finest of any dust on the planet. Negatively charged ions on the edges of these extremely fine mud particles are attracted to the positively charged ions of such heavy metals as cadmium, zinc, mercury, iron, magnesium, lead, cesium and plutonium. This attraction causes the heavy-metal ions to stick to the mud particles.

Another important characteristic of this abyssal mud is its elasticity. Calculations suggest that if we strapped four 55-gallon drums together, added a heavy nose-cone on the end of one drum (to ensure that the drums would not fall sideways), and pushed the whole package off a ship, it would plummet at the rate of about 80 kilometers an hour through three to five kilometers of water and disappear into the mud. Experiments in the deep sea with missile-shaped objects suggest that the hole this package would make on penetrating the muddy seafloor would actually close up. Until we perform more experiments with drums at sea, however, we cannot know for sure.

One area that looks especially attractive as a potential site for burying containers of waste beneath the seafloor is an immense portion of the central North Pacific that is nearly six kilometers deep. The geologic history of this area, which we have assessed from cores of the seafloor, is monumentally dull, a prime criterion for a safe repository.

For the last 65 million years—while the Alps and Himalayas were pushed up, the Isthmus of Panama was closed up, and many ice ages came and went—nothing happened in the central North Pacific basin except the usual unremitting shower of clay dust collecting on the bottom at the rate of a millimeter every few thousand years. With that history, we can predict that the likelihood of a geologic catastrophe occurring and jeopardizing buried containers in this area within the next million years is very low.

But no container lasts forever. What happens when the waste leaks out? There are several barriers inherent in this plan: the waste would be placed well below the limit of animals and thus isolated from the food chain; and gravity and the powerful adhe-

sive quality of the mud would keep the waste containers down. But this is not to say that we know it all. We do not know exactly what the chemical reaction between the sediment and waste will be. We do not know how far, or even if, leaked waste would migrate through the surrounding mud.

The ocean disposal options described here pose intriguing questions to both science and technology. Until the issues are resolved with rigorous research and experimentation, we will never know how practicable they are. As a scientist, a citizen of Planet Earth, and one concerned for the planet's well-being, I think we have little choice but to explore every possible alternative.

If we can't shoot our waste to the stars, can't continue to put it in landfills, and can't place it in the ocean, what are we going to do with it?

> ***"We have little choice but to explore every possible alternative."***

Charles D. Hollister is a Senior Scientist at the Woods Hole Oceanographic Institution, and Vice President of the WHOI Corporation.

Rebuttal

Protecting the Oceans

by Clifton E. Curtis

The 20th anniversary of Earth Day, like a doctor's visit for a physical, provided a special opportunity to examine the health of the planet. In that regard, the ocean—which in my view is the planet's "heart"—is thumping along vibrantly, as a whole. But alarming damage to some of its coastal edges calls for dramatic restorative measures, along with special efforts to keep the disease from spreading.

The oceans are on the receiving end of a tremendous amount of polluting substances. By all accounts, 80 to 90 percent of those pollutants come from land-based sources—pipeline discharges, runoff into coastal waters (both directly and indirectly via rivers), and atmospheric inputs. The remainder comes from ocean dumping, and operational and accidental pollution from vessels and other offshore sources.

In recent years, people have devoted special attention to ending ocean dumping of all toxic wastes. We have made significant progress, considering the global moratorium on radioactive waste dumping at sea that has been in place since 1983; the proposed global phase-out by 1994 of ocean incineration of toxic wastes; regional (North Sea) decisions to end industrial and sewage-sludge dumping at sea; and new national laws, such as the United States prohibiting ocean dumping of industrial wastes and sewage sludge, as well as ocean incineration.

Ocean dumping, however, is only a small fraction of the pollutant loadings. For land-based pollution, the real culprit, we are way behind the curve. Efforts are under way in the United States to deal with land-based pollution much more effectively—

through amendments to the Clean Water Act and Clean Air Act—but even these proposed changes are only a step in the right direction. Much more needs to be done at national and international levels.

But there is a broader issue requiring even greater attention: pollution prevention. When I toured Prince William Sound, just a few weeks after the *Exxon Valdez* oil spill, one of the T-shirts on sale made the point that "An ounce of prevention is worth 11 million gallons of cure." For marine and coastal ecosystems, as well as for the entire planet, that theme is right on target.

We need to adopt two principles: a precautionary approach to waste disposal, and clean production.

However, as long as decision-makers are enticed and lobbied to employ new or better ocean *disposal* options—such as deep-ocean storms to flush toxic waste into sediment mounds or around the globe, or abyssal plains for burial—the health of the oceans and the planet will only worsen. To use an economic analogy, putting toxic waste in the ocean, whatever the disposal method, is akin to a business owner myopically concentrating on increasing profits in the next quarter, while his company's infrastructure and state-of-the art capabilities become less and less stable, jeopardizing long-term survival.

What's needed most of all is the unequivocal adoption and implementation of two related principles: a precautionary approach to waste disposal, and clean production. I'm confident that, eventually, both of these principles will be essential cornerstones to the protection of the oceans and planet. Both are attracting a growing number of adherents, especially in western and northern European countries, as well as the United States. The real issue, though, is whether they will soon enough become accepted practice around the globe.

At present, with a few important exceptions, the benefit of doubt regarding harm posed to the environment still goes to the contaminator. That's a permissive principle, and the so-called "assimilative capacity approach"—referring to the amount of material that can be contained within a body of seawater without producing an unacceptable biological impact—has been the accepted basis for the principle's validity in relation to ocean pollutants.

Unfortunately, while the assimilative capacity concept may have started out as a simple "dilute and disperse" approach to addressing pollutant loadings, it has become unworkable and unable to keep pace given the complexity and pervasive use of chemical compounds. Modern industry produces about 300,000 new chemical compounds each year, and an estimated 70,000 chemical compounds are in daily use. The risk of analytical mistakes is high, given inadequate knowledge. The potential for severe adverse effects also is high, as has been demonstrated in numerous examples of environmental degradation.

As with chemicals, the assimilative capacity approach clearly has been overwhelmed by the diversity of biological species and ecosystems with which it attempts to deal. Scientists are finding, particularly in the deep ocean, far more species than were predicted even 10 years ago. A large number of marine species are as yet unidentified. Of those known to science, we are in the dark about the way many of them function or interact with other species, oceanic processes, or manmade substances. Moreover, there is a wide range of responses to hazardous substances among species and ecosystems, making it very difficult to predict impacts accurately.

With respect to both chemicals and species, assimilative capacity-related testing schemes focus heavily on limited aspects of toxicity, persistence, and bioaccumulation. Those schemes further attest to the high degree of uncertainty underlying any efforts to quantify impacts and predict harm. Continuing to contaminate the oceans, despite such uncertainty, is tantamount to gambling with the environment, and future generations' quality of life.

"We can no longer afford to use the environment as a large-scale laboratory."

In almost every case involving toxic substances, decision-makers do not have enough information to know the effect of these substances in the marine ecosystem. This is precisely what the "precautionary approach" addresses. The approach is best defined by its intent: to safeguard the marine ecosystem by, among other things, eliminating and preventing the release of substances, especially synthetic and persistent ones, if they may cause damage or harmful effects—even when there is inconclusive scientific evidence of a causal link between emissions and effects.

Under this approach, decision-makers faced with scientific uncertainty regarding environmental impact, especially from synthetic and persistent substances, must give the environment the benefit of the doubt. Common sense dictates that we can no longer afford to use the environment as a large-scale laboratory. Such experimentation is unjust when permanent or long-term damage can be done.

Clean production represents the means for implementing the precautionary approach to pollution, in that it is designed to prevent the generation of toxic waste in the first place. Generally stated, it refers to ecologically compatible manufacturing processes that use a minimal amount of raw materials, water, and energy. Embodied in the definition are changes in existing processes, products, and intermediaries to avoid or eliminate toxic waste and toxic products.

To meet clean-production criteria, manufactured goods must be fully compatible with natural ecosystems—from raw material selection, extraction, processing through product manufacture and assemblage, and industrial and household use, to management of

the product at the end of its useful life. Clean production does not include such "end-of-the-pipe" controls as filters and scrubbers, or chemical, physical, and biological treatment. Other excluded measures are those that reduce the volume of waste by incineration or concentration, mask the hazard by dilution, or transfer pollutants from one medium to another.

"Ahem," goes the response of some, "the precautionary approach and clean production sound nice if you are living in ecotopia, but what about the real world?" Yes, toxic wastes do exist, and yes, it will take time before we can have effective precautionary approaches and clean production in place. During the interim, though, the only way to ensure that those principles expeditiously become imbedded, mainstream practices is to require that industries deal with toxic substances and wastes as close as possible to the source of those substances and wastes.

In dealing with toxic wastes, especially synthetic and persistent substances, new technologies that enable effective, protective storage can be brought to bear at or near the source. At the same time, other technologies for recycling those wastes, detoxifying them, or destroying them in closed systems can be employed, either now or as improved technologies come on line. Both technologies ought to be shared with developing countries. Although the technologies are inconsistent, in the longer term, with clean production, they can be used and further refined to help us get over the hump.

In all of this, marine scientists have a very important role to play, one that is at the same time challenging, exciting, and critical to preserving the integrity of the oceans. Much more needs to be known about species and marine ecosystems: how they function; the interactions; the impacts of both natural- and human-derived activities; and how to protect, restore, and preserve marine and coastal ecosystems.

With such a focus—which will require the best talents and skills of the marine scientific community and a concerted shift toward the precautionary approach and clean production—we have a fighting chance. Moreover, if we care about the long haul—which is the only way to go that makes ecological sense for humans, other species, the oceans, and the planet—then we really don't have another choice.

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Congress and Waste Disposal at Sea

by Thomas R. Kitsos and Joan M. Bondareff

Since the early 1970s, Congress has played a major role in developing and implementing U.S. policy on waste disposal at sea. Although Congress has occasionally reacted to initiatives from the Executive Branch, more often than not policy has been molded by strong pressures from coastal residents. Legislation often has been passed despite substantial scientific uncertainty.

In our democratic system of government, when the public demands environmental protection and the scientific community fails to speak with one voice, Congress generally reacts by passing legislation to afford that protection. This has been the case with disposal of wastes at sea.

Congress turned its full attention to the issue of waste disposal at sea in 1972, after decades of ocean dumping. Congress first regulated ocean disposal of wastes when it passed the Marine Protection, Research, and Sanctuaries Act (commonly called the Ocean Dumping Act). That legislation regulated the dumping of all types of materials into ocean waters and prevented or strictly limited the dumping of any material that would adversely affect human health, welfare, the marine environment, ecosystems, or economic potentialities.

Under the Ocean Dumping Act, disposal was prohibited unless the dumper obtained a permit from the Environmental Protection Agency (EPA) and could demonstrate that the materials to be dumped would not "unreasonably degrade or endanger human health or the marine environment." Certain materials, such as radiological, chemical, and biological warfare agents and high-level radioactive wastes were fully banned. The dumping of dredged materials from navigable waters was put under the regulation of the Army Corps of Engineers (see page 63).

The Ocean Dumping Act had its origins in a 1970 report issued by the Council on Environmental Quality (CEQ), which Congress

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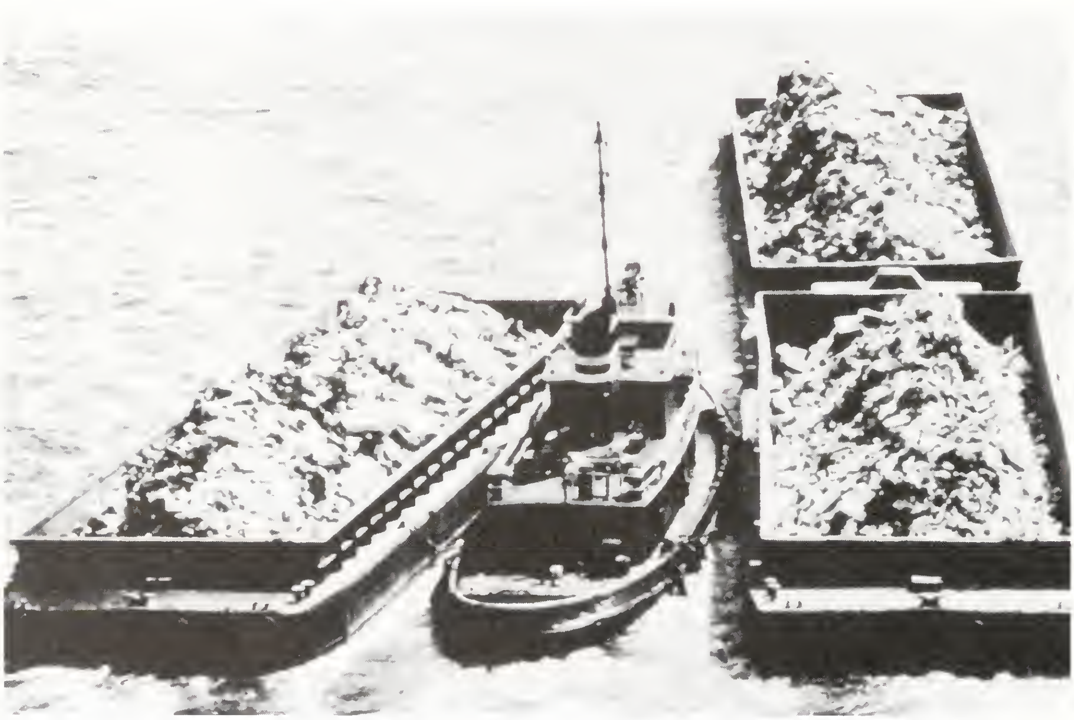
had recently established. The report, entitled *Ocean Dumping—A National Policy*, called for the development of a national and international policy on ocean dumping. The CEQ report also called for ocean dumping of undigested sewage sludge to be stopped immediately and the dumping of treated sewage sludge to be phased out.

The law was enacted during a time when the nation was undergoing a significant rise in environmental consciousness. There was an explosion of environmental legislation and "dead sea" stories began to appear in some newspapers in the Northeast.

The most controversial question facing Congress was the dumping of sewage sludge at sea. Sewage sludge is a by-product of the municipal wastewater treatment process and is permitted to



Tugboat pushes municipal garbage to New York's Greatkills landfill.

be dumped under the 1972 Act, provided it meets environmental standards.

According to a 1987 report by the U.S. Congress Office of Technology Assessment (OTA) entitled *Wastes in Marine Environments*, the amount of sludge dumped in marine waters has increased steadily, from more than 2.5 million wet tonnes in 1959 to about 7.5 million wet tonnes in 1983. The amount of sludge dumped today in the ocean is close to 9 million wet tonnes.

A series of pollution incidents in 1976 forced Congress to take

another look at the ocean dumping of municipal sludge and industrial waste. That summer, large quantities of foul materials washed up on the beaches of Long Island, New York, causing many of that area's largest public beaches to be closed to swimmers. There also was a major fish kill off the East Coast from Long Island to Delaware.

In 1977, as a result of beach closures and fish kills, Congress passed new amendments to the Ocean Dumping Act specifically addressing sludge and industrial waste. The amendments called for an end to ocean dumping of sewage sludge and industrial waste as soon as possible, with no permits to be granted after December 31, 1981. The type of sludge and industrial waste prohibited after 1981 was that which would "unreasonably degrade" or endanger human health or the marine environment. In January of 1977, the EPA issued final regulations stating its intention to stop issuing permits by the end of 1981.

Following the enactment of the 1977 amendments, more than 150 municipalities, including the City of Philadelphia, ended their practice of ocean dumping of municipal sludge, turned to landfilling, and met the 1981 deadline. But New York City, a major user of the ocean for sludge disposal, and several New Jersey municipalities believed they had no economically viable alternative.

A sign of the times in New Jersey.

In 1980, New York City challenged EPA's decision not to renew the city's ocean dumping permit on the grounds that the decision was inconsistent with the intent of the 1977 amendments. New York City argued that the 1977 amendments did not prohibit all dumping of sewage sludge, but only that which would, in the language of the amendments, "unreasonably degrade" the marine environment.

The Federal Court for the Southern District of New York agreed with the city. In a 1981 opinion, the court ruled that EPA had been arbitrary in presuming that the city's sludge did not meet the act's environmental standards. New York City, Nassau County, Westchester County, New York, and six New Jersey municipalities were allowed to continue dumping their sludge in the ocean pursuant to court order.

Although ocean dumping of sewage sludge continued after the 1977 amendments, EPA moved the site for the dumping from the New York Bight Apex, called the 12-mile site, to a new location some 115 nautical miles east of Atlantic City, New Jersey. This site, on the edge of the continental shelf, is called the 106-Mile Dump Site.

Congress codified EPA's administrative decision to move the dump site to deeper waters in the Water Resources Development Act of 1986. This act required all dumpers to move their operations to the 106 site by December 31, 1987. It also prohibited any new dumpers from using the site. All dumpers met the deadline for moving their operations, although it meant, in New York City's case, the acquisition of larger barges for transporting the sludge to the new site.

The summer of 1987 was another bad summer for U.S. coastal communities. Public beaches in numerous New Jersey townships were closed as a result of medical debris washing ashore, high bacteria counts in the water, and sewage plant overflows. The public was particularly aghast at the sight of needles on public beaches, and naturally concerned about the risk of contracting contagious diseases. The effect on the New Jersey tourist economy was disastrous, the lost business estimated to be in the billions of dollars. The public also witnessed and mourned an unusually high number of dolphins dying and washing up along the Atlantic coast.

The sight of needles and other medical debris on beaches in the late 1980s contributed to public concern.

Although the dolphin deaths were subsequently attributed to a naturally occurring toxin, the possibility that the incidents were exacerbated by high levels of contaminants in the animals could not be ruled out. In addition, fishermen near the 106 site reported shell diseases in fish, which they attributed to the dumping of sludge at the site. The clamor for Congress to do something was deafening.

As a result, Congress again re-examined the Ocean Dumping Act. This time, in the Ocean Dumping Ban Act of 1988, Congress made clear what had not been clear in the 1977 amendments—all ocean dumping of sewage sludge and industrial waste, whether or not it unreasonably degraded the marine environment, would cease after December 31, 1991.

Moreover, all dumpers would have to enter into enforceable agreements with EPA in which they had to commit to specific schedules to phase out ocean dumping of sewage sludge or face stiff penalties. By the time of the enactment of the 1988 amendments, the remaining industrial waste dumpers had agreed to stop using the ocean.

The penalties start at $600 a ton for any sludge dumped after the 1991 deadline, and escalate incrementally in each subsequent year. The penalties are not strictly punitive; dumpers will be allowed to retain a certain percentage of the penalties if they dedicate the money to developing land-based alternatives.

New Jersey plans to landfill its sludge to meet the deadline and, in the long term, to construct incinerators to burn dewatered sludge. New York City, which dumps close to 5.3 million wet tonnes of sludge a year at the 106 site, has agreed to phase out ocean dumping of 20 percent of its sludge by the 1991 deadline, with the remainder by June 30, 1992 (subject to the payment of civil penalties). The city is studying all possible options for long-term management of the sludge. The design of eight dewatering facilities is now under way.

The Greenpeace slogan on the infamous NYC "garbage barge" reflects public concern over ocean dumping. The barge was rejected by a number of countries in Central America and the Caribbean.

Although it will soon be illegal to dump sludge and industrial waste in the ocean, we are continuing to use the ocean as a disposal medium for dredged materials. According to the OTA report, an annual average of about 180 million wet tonnes of dredged material is disposed of in the marine environment: about two-thirds in estuaries, one-sixth in coastal waters, and one-sixth in the open ocean.

There is growing public concern about the presence of contaminated sediments in the materials dredged from ports and harbors. The sediments are contaminated by metals and organic chemicals that settle as a result of industrial discharges and runoff of pollutants. Congress is beginning to examine the issue of contaminated sediments to determine if additional controls on their ocean disposal are required.

The views expressed in this article are solely those of the authors, and do not necessarily reflect the views of the members of the U.S. House of Representatives Merchant Marine and Fisheries Committee.

In the area of environmental protection, there has been no clear consensus among marine scientists about what caused past pollution incidents or, if there is, it has not been effectively communicated to Congress. What is clear is that the capacity of the oceans to absorb waste materials is a matter of continuing debate among oceanographers, with no apparent resolution in sight.

Given this debate, a cautious and responsible legislative response is to ban the activity until sufficient information becomes available. We have seen this approach in recent congressional reactions to offshore oil and gas development, ocean incineration, and the dumping of sludge and industrial waste at sea.

For now, Congress has established a clear policy prohibiting the ocean disposal of sewage sludge, industrial waste, high-level radioactive waste, chemical and biological warfare agents, and the ocean incineration of toxic materials. Opening up the debate about changing this policy will not be easy.

Yet, Congress is a dynamic institution, affected by new technological developments, advances in science, and hard data about risks and benefits. No policy debate is closed forever. Increased restrictions on landfills will create its own environmental cost-benefit calculations that could, someday, require a revisiting of this established policy.

A Brief History of Ocean Disposal

by Iver W. Duedall

During the last 20 years, the open ocean has come under increasing pressure from waste disposal. Meanwhile, the coastal ocean continues to receive greater amounts of contaminants from outfalls and land runoff. Because water and marine life have no sense of political boundaries, international organizations play a vital role in providing discussion, regulation, and policy on what society disposes of in the ocean.

Historically, most coastal countries used the sea for waste disposal. It was generally the most economic way to manage the waste, since land usually had, and still has, a high price tag while the sea has no private owner in the normal sense. In addition, dilution processes served the illusion that dumping at sea does not cause any permanent damage. So why risk contaminating land or drinking water with wastes if the sea is close by?

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Dredged-material (•), sewage-sludge ( ), and industrial-waste disposal sites (+), and regions of drilling-fluid discharge (shaded areas).

For some countries, the systematic disposal of wastes into the ocean has a long and fairly well-documented history. Until very recently, the New York metropolitan region always considered the ocean as disposal grounds for much of its sewage sludges, dredged material, garbage, demolition material, and street sweepings. For decades, Britain disposed of sewage sludges and coal wastes, including colliery waste-shale and power plant fly ash, at sea.

The most common form of ocean dumping today is disposal from ships or barges, but specially constructed incineration vessels also burn liquid organic wastes such as PCBs and other organohalogens. The list of wastes dumped at sea is very long, and is topped by dredged material, industrial waste (usually acid-iron and alkaline waste, scrap metal, fish by-products, coal ash, and flue-gas desulfurization sludges), and sewage sludge.

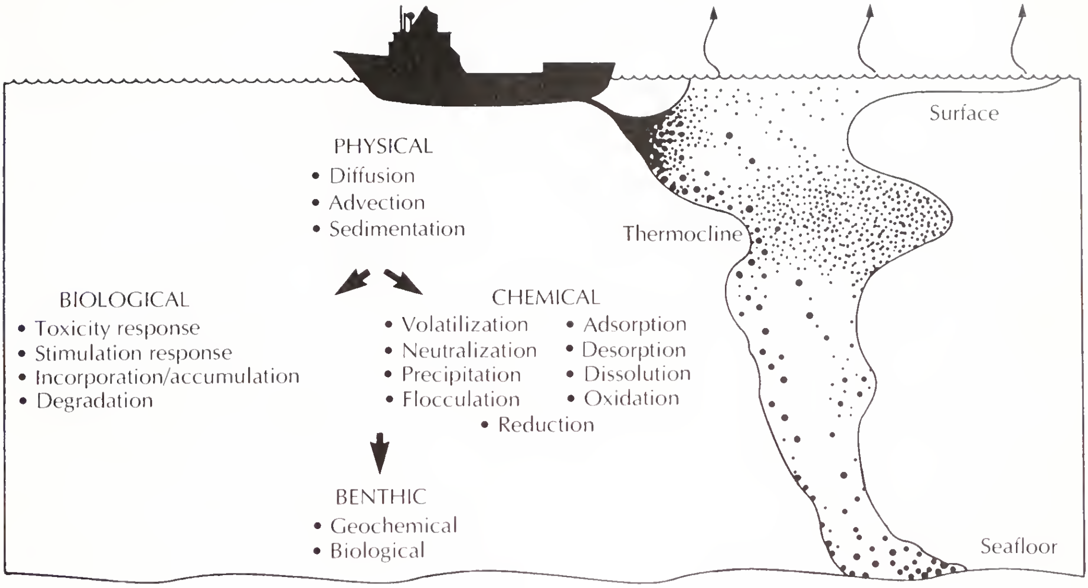
One disposal option for liquid organic wastes is to burn them at sea in specially designed ships.

Worldwide concern about effects of ocean dumping did not exist prior to 1960. Earlier environmental interest focused on the pollution of streams, rivers, lakes, and estuaries from outfalls and land-based emissions such as industrial waste, agricultural runoff, and, in general, very careless waste management practices.

In 1967, interest in protecting the ocean from chemical pollution, industrial and transportation disasters, and ocean dumping began to climb after the *Torrey Canyon* oil spill off the Cornish coast. According to Douglas M. Johnston, editor of the 1981 book *The Environmental Law of the Sea*, this disaster sparked a number of international meetings dealing with basic issues of ocean pollution, including the need to develop policy, regulation, and an international infrastructure to deal with ocean dumping, exclusive of such manmade disasters as oil spills.

In the United States, the evolution of ocean dumping regulation, policy, and research took a huge jump forward in 1970, when the Council on Environmental Quality published its landmark report (see page 23). This was the first concerted scientific effort to determine the fate and effects of wastes dumped at sea; and had the report not been published, it was likely that U.S. ocean dumping would have increased. However, in the 20 years since the report, we have seen changes in federal legislation and policy leading to the cessation of several ocean dumpsites, comprehensive scientific research on the fates and effects of waste dumped at sea, and heightened public interest due to well-publicized beach closings.

The U.S. Environmental Protection Agency (EPA) presently has designated about 109 ocean dumpsites that fall into two categories: interim and noninterim. The 46 interim sites received their desig-



Many physical processes will affect the distribution and fate of waste in the water column.

nations on the basis of historical usage. While EPA reviews of the 63 noninterim sites are yet to be completed, the agency has found that the sites meet ocean-dumpsite regulations and criteria. Ninety-five percent of the sites are used for the disposal of dredged material (see page 63).

In June, 1971, the Inter-Governmental Working Group on Marine Pollution (IWGMP, established by the UN Conference on the Human Environment) met in London and expressed the need for an international agreement to regulate dumping at sea. The U.S. delegation submitted a draft of a document known as the "Convention for Regulation of Transportation for Ocean Dumping." The IWGMP encouraged member states of the United Nations to give written opinions, and that November held a second meeting in Ottawa, Canada.

Several of the draft articles on ocean dumping were accepted at this second meeting. The draft was subjected to further revisions at an April, 1972, meeting in Reykjavík, Iceland; at two meetings held later in the year in Britain; and at the 1972 Conference on the Human Environment held in Stockholm, Sweden. Through this process, the revised draft became the London Dumping Convention (LDC), which entered into force on 30 August 1975.

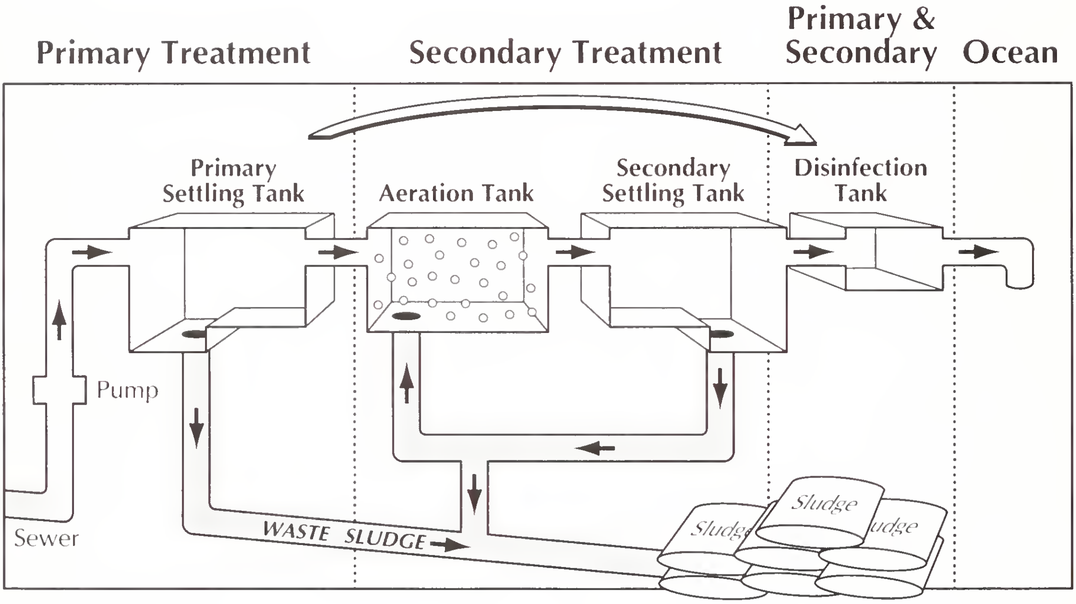
As of 25 December 1989, 64 countries, the so-called "contracting states," ratified or acceded to the LDC. Areas under the convention's jurisdiction include both territorial seas and high seas. These

areas are further defined to include all marine waters except internal waters of contracting states.

The LDC defines ocean dumping as:

- *Any deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other manmade structures at sea.*
- *Any deliberate disposal at sea of vessels, aircraft, platforms or other manmade structures at sea.*

The at-sea discharge of primary, secondary, and tertiary treated sewage effluent (and sewage sludge off the southern California coast) from outfalls is not considered ocean dumping; nor is the disposal of incidental material such as sea- or freshwater used in the operation of vessels, aircraft, and platforms or other structures.



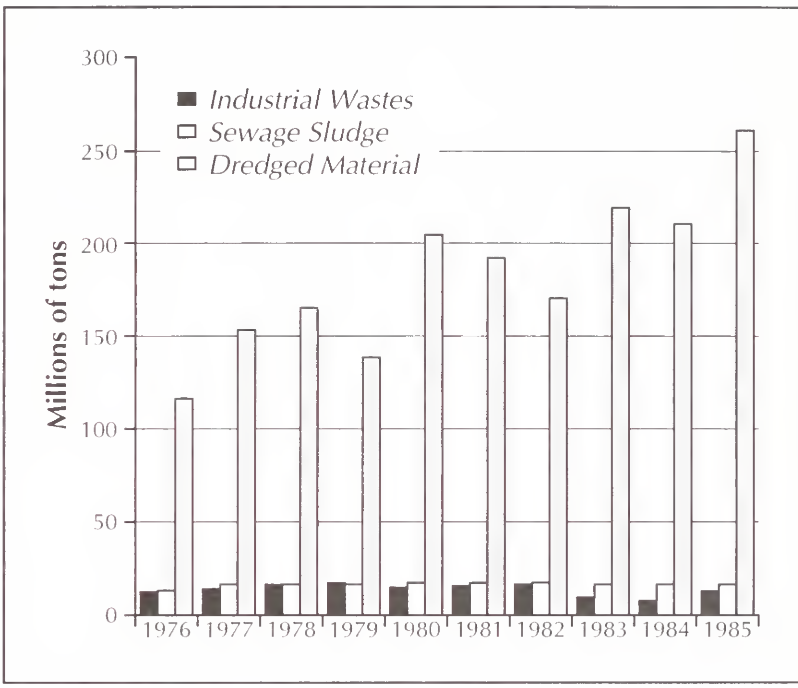
Municipal effluent and sludge go through varying stages of treatment before they are reused or disposed.

At-sea discharge of mining and smelting wastes from exploration, exploitation, and associated offshore processing of seabed minerals is similarly not considered ocean dumping.

The LDC uses the black-list/grey-list format for categorizing substances for permit purposes. Annex I of the LDC defines black-list substances while Annex II defines grey-list substances (see pages 34 and 35). Dumping of black-list substances is prohibited. Industries affected by the ban include pesticide, chemical, and rope manufacturing; electroplating; and domestic and military nuclear.

The grey-list substances also are produced and/or used by an array of industries, and can be dumped only after obtaining a special permit. Dumping of all other substances requires a general permit from the appropriate federal administrative organization within the contracting state.

Accurate worldwide records on the amounts of wastes disposed at sea prior to 1976 are virtually impossible to obtain. However, as a result of the international activities leading to conventions or agreements, information is becoming available on the number of ocean dumping permits issued by many countries, dumpsite locations, and the kinds and quantities of wastes dumped. Worldwide, the national authorities of the contracting states annually issue a total of about 50 permits for the ocean disposal of sewage sludge, 150 for industrial wastes, 380 for dredged material, and 50 for other materials—such as ships, low-level nuclear wastes, and the incineration of chlorinated hydrocarbons.



Comparison of quantities of sewage sludge, industrial wastes, and dredged material permitted for ocean disposal by the London Dumping Convention. "The reader should be warned against over-interpretation of the data which for several reasons must be considered approximate."

LDC policy on ocean dumping is similar to that of such other regional agreements as the Barcelona, Helsinki, and Oslo conventions. The Barcelona and Helsinki conventions prohibit the disposal of all forms of nuclear waste, organosilicon compounds, and acid and alkaline compounds that are not rapidly rendered harmless by processes occurring at sea. Other organizations that address this issue include the Bonn Agreement, the Kuwait Final Act, the Paris Commission, UN Environment Program's (UNEP) Regional Seas Program, and the Joint Group of Experts on the Scientific Aspects of Marine Pollution.

The International Maritime Organization (IMO, previously called the Inter-Governmental Maritime Consultative Organization) provides the administrative mechanism for cooperation among the LDC's contracting states. The IMO's Marine Environmental Division, located in London, collects and disseminates infor-

(continued on page 36)

Substances controlled by the

Black list: Annex I

1. Organohalogen compounds

2. Mercury and mercury compounds

3. Cadmium and cadmium compounds

4. Persistent plastics and other persistent synthetic materials, for example, netting and ropes, which may float or may remain in suspension in the sea in such a manner as to interfere materially with fishing, navigation, or other legitimate uses of the sea.

5. Crude oil, fuel oil, heavy diesel oil, lubricating oils, hydraulic fluids, and mixtures containing any of these, taken on board for the purpose of dumping.

6. High-level radioactive wastes or other high-level radioactive matter, defined on public health, biological, or other grounds, by the competent international body in this field, at present the International Atomic Energy Agency, as unsuitable for dumping at sea.

7. Materials in whatever form (such as solids, liquids, semi-liquids, gases, or in a living state) produced for biological and chemical warfare.

8. The preceding paragraphs of this annex do not apply to substances which are rapidly rendered harmless by physical, chemical, or biological processes in the sea provided they do not: (i) make edible marine organisms unpalatable, or (ii) endanger human health or that of domestic animals.

The consultative procedure provided for under Article XIV should be followed by a Party if there is doubt about the harmlessness of the substance.

9. This Annex does not apply to wastes or other materials (such as sewage sludges and dredged spoils) containing the matters referred to in paragraphs 1 to 5 above as trace contaminants. Such wastes shall be subject to the provisions of Annexes II and III as appropriate.

10. Paragraphs 1 and 5 of the Annex do not apply to the disposal of wastes or other matter referred to in these paragraphs by means of incineration at sea. Incineration of such wastes or other matter at sea requires a prior special permit. In the issue of special permits for incineration the Contracting Parties shall apply the Regulations for the Control of Incineration of Wastes and Other Matter at Sea set forth in the Addendum to this Annex (which shall constitute an integral part of this Annex) and take full account of the Technical Guidelines on the Control of Incineration of Wastes and Other Matter at Sea adopted by the Contracting Parties in consultation.

London Dumping Convention

Grey list: Annex II

The following substances and materials require special permits, issued only according to the articles of the LDC.

A. Wastes containing significant amounts of the matters listed below:

arsenic, lead, copper, zinc, and their compounds

organosilicon compounds

cyanides

fluorides

pesticides and their by-products not covered in Annex I

B. In the issue of permits for the dumping of large quantities of acids and alkalis, consideration shall be given to the possible presence in such wastes of the substances listed in paragraph A, and to beryllium, chromium, nickel, vanadium, and their compounds.

C. Containers, scrap metal, and other bulky wastes liable to sink to the sea bottom which may present a serious obstacle to fishing or navigation.

D. Radioactive wastes or other radioactive matter not included in Annex I. In the issue of permits for the dumping of this matter, the contracting parties should take full account of the recommendations of the competent international body in this field, at present the International Atomic Energy Agency.

E. In the issue of special permits for the incineration of substances and materials listed in this Annex, the Contracting Parties shall apply the Regulations for the Control of Incineration of Wastes and Other Matter at Sea set forth in the addendum to Annex I and take full account of the Technical Guidelines on the Control of Incineration of Wastes and Other Matter at Sea adopted by the Contracting Parties in consultation, to the extent specified in these Regulations and Guidelines.

(From the Final Act of the LDC, Office of the London Dumping Convention, International Maritime Organization, London)

mation through the Office of the LDC on all aspects of dumping at sea by contracting states. The division also convenes the annual LDC consultative and scientific meetings.

Delegations from the contracting parties and observers from noncontracting parties, UN organizations, and various intergovernmental and nongovernmental organizations attend the consultative meetings. For example, in 1989 at the 12th Consultative Meeting of the Contracting Parties to the LDC, representatives of Barbados, Cyprus, Egypt, and Liberia attended as noncontracting observers. Intergovernmental organizations were represented by such groups as UNEP, the Intergovernmental Oceanographic Commission, and the Organization for Economic Cooperation and Development's Nuclear Energy Agency. Nongovernmental organizations that sent observers included the International Association of Ports and Harbors, Friends of the Earth International, the World Conservation Union, and the Oil Industry International Exploration and Production Forum.

"If past ocean-dumping practices are any indication, ocean dumping is bound to continue."

The LDC Scientific Group on Dumping meets annually, but not at the same time as the consultative group, and attracts similar observers. Items discussed at the April, 1989, meeting included reports on annexes, field verification of laboratory tests, monitoring and control of dumping and incineration at sea, disposal of offshore structures, processes and procedures for managing wastes dumped at sea, and cooperation and information exchange.

The large number of organizations attending both the consultative and scientific meetings of the LDC demonstrate the strong international interest in issues of ocean dumping. The meetings provide the inter- and nongovernmental organizations with opportunities to present their points of view.

If past ocean-dumping practices are any indication, ocean dumping is bound to continue. Countries continue to use the sea for the disposal of wastes, although North Sea countries intend to halt all at-sea dumping except for dredged material. Interest in the health of the sea is now a worldwide issue and therefore each ocean-dumping proposal should be considered cautiously.

The volume of dredged material for disposal has been steadily increasing and probably will continue to do so. While the disposal of industrial waste seems to be declining, this may be temporary as companies that used the sea for waste disposal make adjustments, such as relocating to regions where public or legal opposition to ocean dumping does not exist. For sewage sludge, only two countries, the United States and Britain, dump large quantities of sludge into the ocean, although the United States plans to end at-sea sludge disposal by the end of 1991 and Britain will phase it out by 1998. Britain also will end at-sea dumping of industrial waste as soon as 1992, but no later than 1993.

As the ocean receives less of the "traditional" forms of waste,

new forms appear for consideration. There is the problem of decommissioned offshore platforms and structures: should they be disposed of at sea or not? The 12th consultative meeting of the LDC discussed whether toppling such structures and redesignating them as artificial reefs is really "dumping." The meeting also heard discussions on the possible ocean disposal of decommissioned nuclear submarines, and proposals for restructuring the annexes.

Most countries that use the sea for waste disposal are industrialized and enjoy a high standard of living. Developing countries will likely take a more active interest in ocean dumping as they industrialize and improve land-based sanitation and waste management.

These issues will be best faced by international organizations, such as the LDC, which can provide information on alternatives to dumping, and the expected fate and effects of the wastes in the ocean, through either its own organization or the contracting states. In this regard, the eighth consultative meeting of the LDC received an important report from "Task Team 2000," the LDC's policy-planning group, that identified nine feasible mitigative measures (see page 38) that could protect the marine environment.

The impact of international scientific and political activities on ocean dumping during the 15 to 20 years since publication of the

Measures for reducing environmental pressures on the ocean

- *Wherever possible recycle and reuse waste products.*
- *Treat wastes that cannot be recycled or reused at the source to the extent feasible.*
- *Use pesticides and fertilizers in such a fashion that they do not enter the marine environment.*
- *Use sea disposal, whether by outfall or by dumping, only for those materials that are compatible with the marine environment.*
- *Use locations for sea disposal of wastes that will not interfere with other uses of the sea.*
- *Use waste disposal practices at sea that minimize local impacts at the point of disposal.*
- *Carefully evaluate the potential environmental impacts of new developments and seek to mitigate adverse impacts.*
- *Monitor the health of the oceans on a continuing worldwide basis.*
- *Manage the use of the resources of the sea so as to prevent depletion of resources on a worldwide basis.*

(From the Office of the London Dumping Convention, International Maritime Organization, London.)

Council on Environmental Quality report and formation of the LDC has been rapid and productive. Some industries are using cleaner technologies and some countries are either taking a precautionary view on ocean dumping, or eliminating it altogether. Such steps could lead to a more optimistic prediction that the oceans will become cleaner. However, ocean outfalls, nonpoint sources, catastrophic oil spills, and, in general, overuse and exploitation of coastal regions are major threats still to be reckoned with.

Acknowledgments
I am very thankful to Manfred Nauke and John Karau for their continued help over the years in providing information on activities of the LDC, and for reading and making comments on this report; I am also very thankful to Annette Bernard for her help in typing the manuscript.

Effects of Wastes on the Ocean: The Coastal Example

by Judith E. McDowell Capuzzo

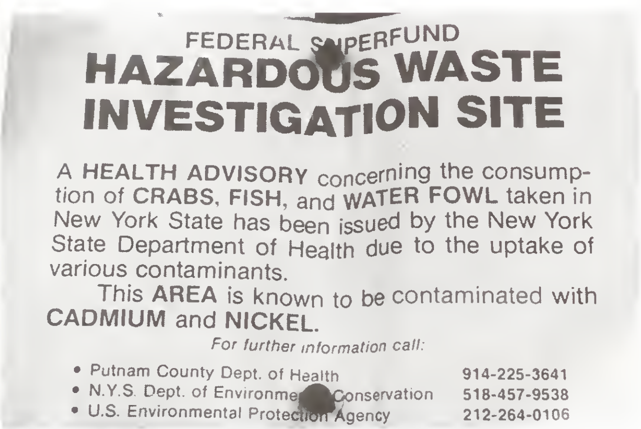
Extending from the shore to the edge of the continental shelf, the coastal ocean is one of the most productive ecosystems in the world. Coastal areas provide 50 percent of the world's fisheries harvests, and are the breeding and nursery grounds of many commercially important species.

Dumping acid-iron wastes in coastal waters, as practiced in the New York Bight in the early 1980s, is no longer allowed in the United States. However, it still goes on elsewhere in the world.

As our population grows, demands on coastal resources increase. Uncontrolled waste disposal in coastal areas degrades the waters, and compromises fishing and mariculture. Studying effects of waste already disposed in coastal areas can help us formulate environmentally sound plans for ocean waste disposal, and pinpoint critically needed research.

The coastal ocean receives a wide range of contaminants from society's refuse, including discharges from industrial and municipal wastes, dredged material, atmospheric fallout, and polluted rivers. Environmental concern for ocean dumping of sewage sludge and medical wastes has dominated news headlines and environmental legislation in recent years.

In reality, contamination from sewage sludge is only a small fraction of all pollution entering coastal waters. Sewage and industrial effluents, land runoff, and dredged materials are larger sources of such persistent and dangerous chemicals as polychlorinated biphenyls and polynuclear aromatic hydrocarbons (PCBs and PAHs, see page 54).



The distribution, fate, and effects of contaminants in coastal marine environments are governed by natural processes that influence their persistence in the ocean and their availability to marine animals. Organisms may accumulate contaminants from their food or absorb them from the surrounding water or sediment. Over time, certain chemicals build up within an animal—a process called bioaccumulation. If this animal is eaten by another, then the chemical can be passed up the food chain.

Many biologically harmful contaminants bind to floating particles, and then settle into the sediment. There are numerous examples of sediment deposits in coastal areas that reflect waste disposal histories. In Massachusetts, for example, high levels of PCBs in New Bedford Harbor and PAHs in Boston Harbor come from decades of local waste production and disposal.

The principal strategies for ocean disposal are containment and dispersal. Containment is not feasible for the disposal of large volumes of waste. Exceptions to this rule are extremely hazardous refuse, such as high-level radioactive waste, that may be contained before disposal, and dredged materials that can be dropped into a submarine pit and then capped. As for dispersal, the ocean offers some natural mechanisms: strong bottom currents pick up and

transport materials, which are broken down and recycled in biogeochemical cycles.

But the ocean varies, and some areas have stronger or more consistent currents than others. Studies show that in coastal dumpsites with low dispersion, sewage sludge can cause high levels of organic enrichment. This can have negative impacts on benthic, or bottom-dwelling, communities: oxygen levels drop and there is reduced diversity of animals. On the other hand, there have been no apparent changes in benthic communities at highly dispersive dumpsites. These differences suggest that dispersal may not only be the easiest disposal option, but also the best.

Runoff from agricultural lands can carry pesticides and other pollutants into estuaries and coastal waters.

But organic enrichment is only one of many major concerns. Two others are uptake and accumulation of pathogens or toxic contaminants in resources destined for people's dinner tables, and toxic effects on the survival and reproduction of marine organisms—effects that lead to adverse impacts on marine ecosystems. To minimize these risks, wastes should be placed where strong horizontal dispersion will spread materials far and wide.

As toxic chemicals make their way through marine food chains, they may lead to specific ecological changes at each trophic level, or result in tainted seafood. Some of the most dangerous contaminants are metals, halogenated hydrocarbons, and other organic compounds including petroleum hydrocarbons from accidental oil spills, municipal discharges, and urban runoff. These contaminants are linked to human health effects.

Ecological concerns include changes in species distributions and abundance, habitats, and biogeochemical cycles. Commercially important species or populations might diminish because of reproductive or developmental failure, habitat destruction, or new interactions with other species.

Habitat alteration and its impact on fisheries is becoming an extremely important ecological issue. The impact of any particular

contaminant depends largely on its concentration and transport. The most serious ecological and human health concerns are limited to localized areas where decades of disposal have caused high levels of contamination.

An example of long-term localized pollution is illustrated in a recent chemical analysis of fish and shellfish from New England. The study covered data spanning 25 years and was commissioned by the Coast Alliance, a consortium of environmental advocacy groups. My colleagues and I collected data sets from various regions and species. The worst cases were found in urban harbors. Fish and shellfish from these coastal areas were highly contaminated.

Chemical contamination of coastal waters has put commercial and recreational fisheries at risk.

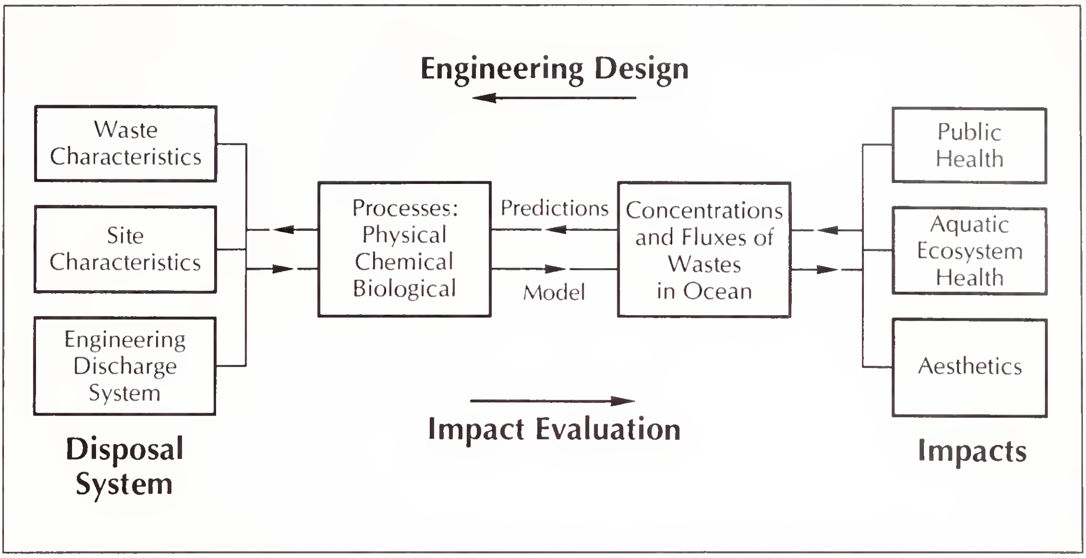
If urban discharges continue unabated, even clean, remote areas could become contaminated. However, when the use or production of a toxin has been controlled (as with the insecticide, DDT, which was banned in the late 1960s) contaminant levels decline over time. With highly persistent compounds like PCBs, this reduction may take many years.

Chemical contamination has recently led to several fishery closures along the U.S. coasts. For example, in 1979, the Commonwealth of Massachusetts closed approximately 72 square kilometers of Buzzards Bay to finfishing and shellfishing because of PCB contamination; in the early 1980s, the State of California developed health advisories warning the public against frequent consumption of fish caught off Southern California; in 1986, the states of New York and Rhode Island closed their commercial and recreational striped bass fisheries as a result of PCB contamination; and in 1988, the Massachusetts Department of Public Health warned against eating tomalley (the gooey but tasty green organ known to biologists as the "hepatopancreas") of lobsters from Quincy Bay. These actions illustrate a growing concern for the impact of chemical contamination on resources in coastal waters.

Defining the risk of food-chain contamination requires an understanding of potential transfer routes to the human consumer. Contaminants that can cause mutations, cancer, or other ill-health effects in humans are of particular concern. These include chlorinated hydrocarbons, petroleum hydrocarbons, and heavy metals such as mercury, lead, and cadmium.

Exposure standards for human health exist for only a few contaminants, such as PCBs, mercury, and DDT. There is considerable variation in policy recommendations from different agencies regarding seafood safety issues.

Policy inconsistencies result from different methods of analysis and risk assessment, and in the inherent assumptions used in establishing ostensibly safe limits. In such pollution studies as those conducted in Quincy Bay, recommendations regarding seafood consumption issued by the U.S. Environmental Protection



Engineering design and environmental objectives of waste disposal. (U.S. Natural Resources Council, 1984)

Agency are in direct conflict with recommendations of safe limits made by the U.S. Food and Drug Administration. To alleviate public concern over the safety of their seafood supply, state and federal agencies must coordinate sampling and analytical protocols as well as risk assessment and regulatory guidance.

How can society use the oceans for waste disposal without harming the marine environment or fisheries resources? The first step in developing wise management of ocean-disposal policy is to control more tightly the production and utilization of toxic chemicals, and reduce their amounts in wastes. To handle the unavoidable waste that remains, ocean disposal system designs should incorporate the currents and dispersive characteristics of the receiving waters. Offshore waste disposal has several advantages over nearshore disposal: greater dilution and dispersion, and a reduced chance for the contaminants to reach humans through the food chain.

To evaluate the environmental impacts of waste discharges requires an understanding of how contaminants are distributed over space and time; in which parts of the ecosystem they collect (for example, sediment or organisms); and the damage caused by toxic accumulation. Thus, we need to develop impact assessment methods that couple an understanding of contaminant distribution and the mechanisms of toxic action.

To understand long-term impacts of waste disposal in the oceans, many questions need answering: How long will contaminants persist in the marine environment? What is the uptake by commercially important fish and shellfish? What are the sublethal effects on marine organisms?

To answer such questions, we also need to know:

- *the physical processes—specifically, currents—that influence contaminant distribution;*
- *the chemical processes that influence availability, persistence, and degradation of these materials in sediments and water; and*
- *the long-term biological effects that alter the stability of animal populations and the consequences of those effects on recreational and commercial fisheries.*

The first two aspects are important for establishing realistic exposure scenarios—in time and space—and the third is important for linking ecological effects to the contamination of resources.

But these questions cannot be answered by scientists in any one field. Ecologists, toxicologists, and oceanographers must all cooperate to develop "the big picture." It is only through multidisciplinary studies that we will come to understand the causal relationship between pollution and coastal degradation, or develop predictive approaches to environmental monitoring.

The oceans may continue to provide a disposal option for society's wastes, but only if sites are properly selected, managed, and monitored. As we approach the 21st century, it is essential that scientists, environmental managers, policymakers, engineers, and legislators work together to develop environmentally sound waste-disposal options.

Judith E. McDowell Capuzzo is a Senior Scientist in the Biology Department at the Woods Hole Oceanographic Institution.

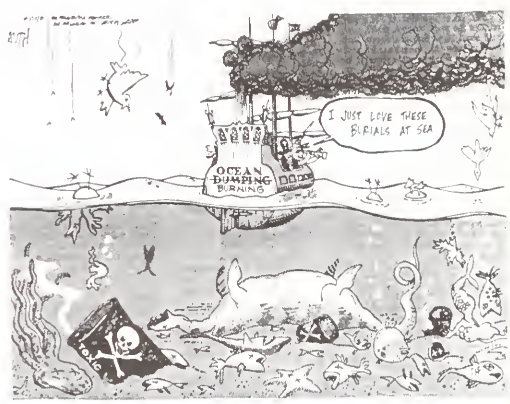
"I don't know why I don't care about the bottom of the ocean, but I don't."

Mid 1980s

Cartoon reflecting the public interest in using the deep ocean for waste disposal, and focusing on the perceived general lack of interest in the deep ocean.

Editorial Cartoons and Public Perception

by Michael A. Champ



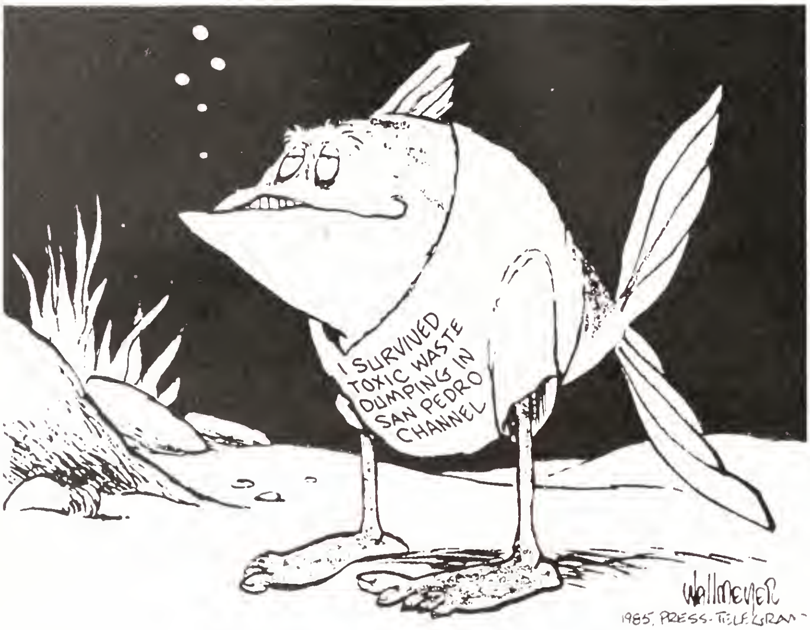
Late 1970s

Cartoon that marked the shift of people's interest from humankind to the ecosystem and biological effects.

The pollution cartoons reproduced here demonstrate the power of illustration to present information, ideas, and concepts. Cartoons contribute an artist's interpretation of society's beliefs, moods, or knowledge.

Early 1970s

Cartoon depicting the sludge monster coming ashore on Long Island and New Jersey beaches.



March 1985

These cartoons, spanning 20 years, reflect the public's fear of a catastrophic degradation of the marine environment. This fear is thus a reality that policy- and decision-makers must deal with when developing waste management strategies. Cartoons are a constant reminder that research cannot be an end unto itself. Informing the public is at least as important as research itself.

Cartoons also reflect what the public knows, does not know, or does not want to know. In most cases, a cartoon's purpose is to educate, enlighten, and stimulate response—be it anger, frustration, or sad laughter. The cartoon may exaggerate a point for inherent humor, or truth, or both.

'Toons cannot be closely or repetitively examined because they have only one purpose—to capture 100 percent of our attention just once. On closer examination, we often wonder why we laughed, because the point is so simple.

For example, floating dead fish have never been found following ocean dumping of acid wastes. Fish swim away from the waste plume into uncontaminated waters and the acid wastes are quickly diluted to below acutely toxic (short-term exposure) levels.

However, if the same fish were to stay in the waste stream they would die in a very short time. A cartoon depicting dead fish

March 1985

associated with ocean dumping is an extension of these two truths, and an assumption that two truths make a third. Nevertheless, such cartoons do represent a public outcry not to let coastal marine pollution or ocean dumping create vast areas of dead marine life.

There are some world-class environmental editorial cartoonists today. The illustrations here are from my personal collection of some 200 cartoons on marine pollution and ocean waste disposal. Many have been sent to me by friends from all over the English-speaking world. The ones selected here are my favorites.

Michael A. Champ is President of Environmental Systems Development, Inc., in Falls Church, Virginia. He has spent some 20 years in the waste management field, including senior advisory positions at the National Science Foundation, the Environmental Protection Agency, and the National Oceanic and Atmospheric Administration.

"Business was fine until the Trades Description bloke poked his bloomin' nose in."

June 1987

"It's not my idea of a dip in the briny!"

July 1983

"All my life I dreamed of living on a desert isle, far from all trace of civilization..."

May 1984

"Keep it up, Fred! There's plenty more rubbish coming in with the tide!"

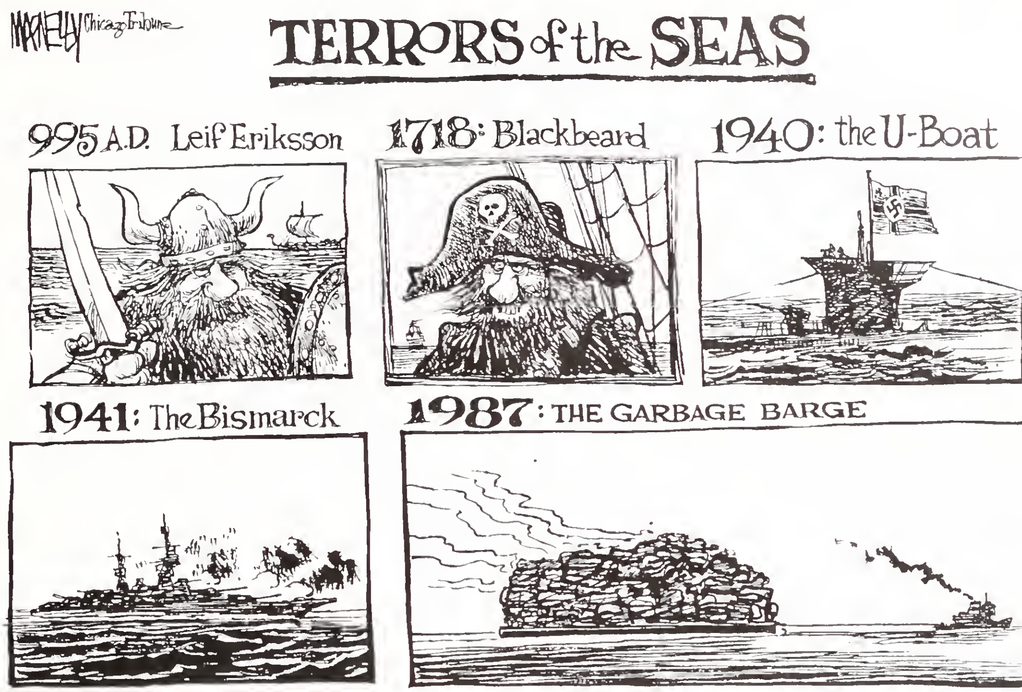
August 1982

October 1986

"Let's get out of here–the canary's dead!"

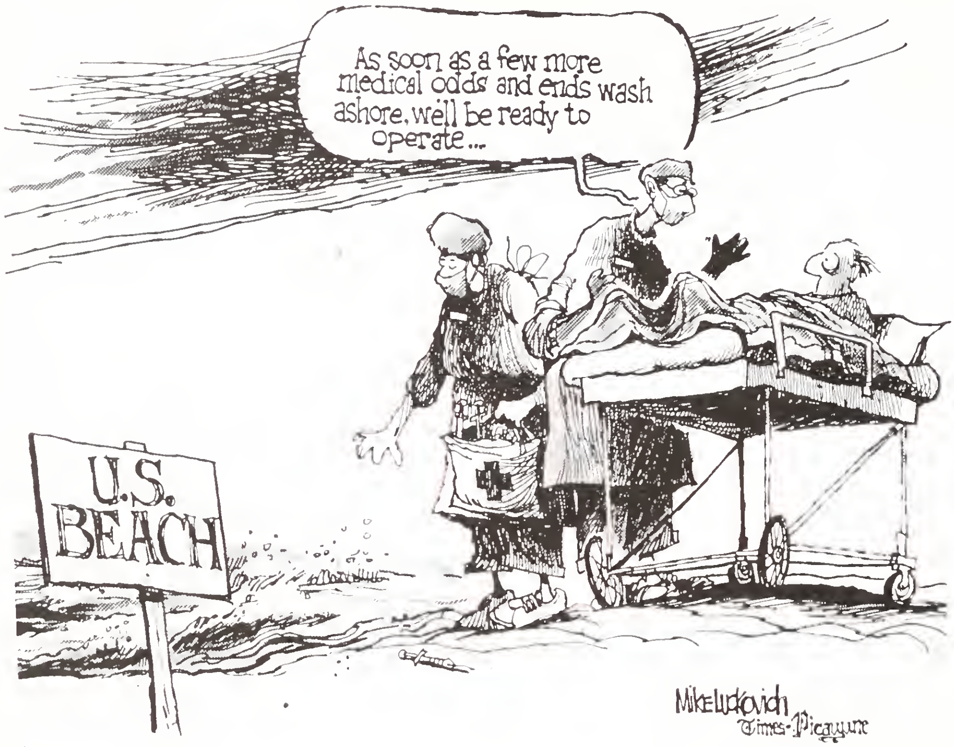
February 1977

"I'm keen on the environment too—but I like to keep my job and my private life separate"

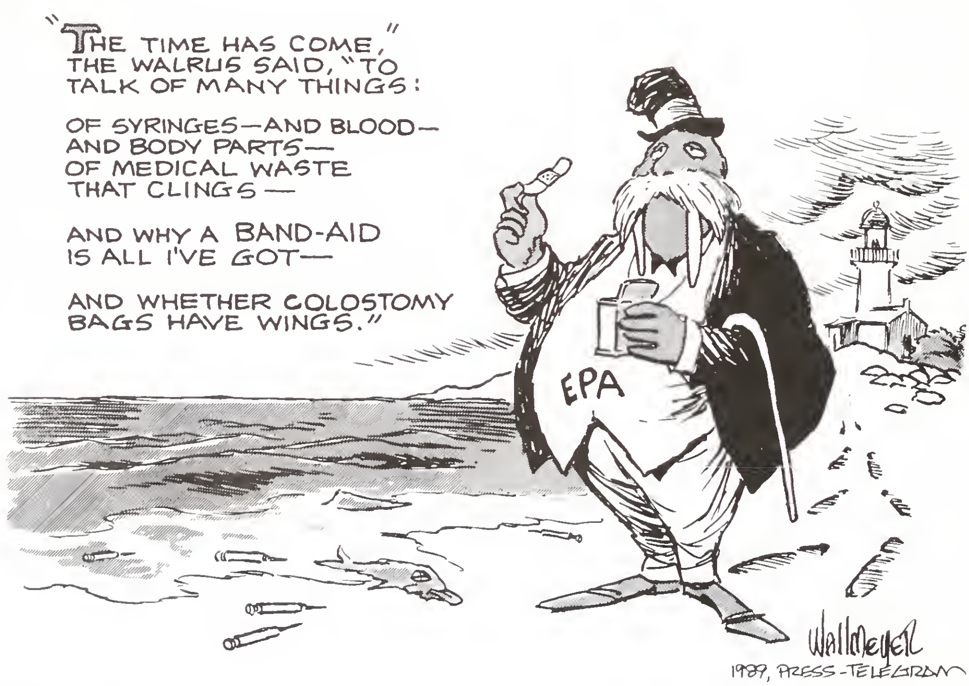


May 1987

September 1988



August 1988



March 1989

WASHINGTOON — *Mark Alan Stamaty*

August 1988

Detecting the Biological Effects of Deep-Sea Waste Disposal

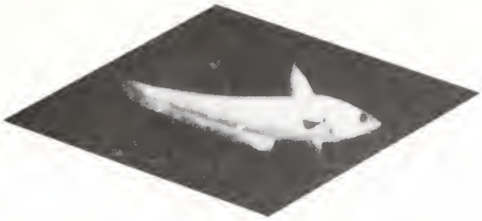
by John J. Stegeman

Maintaining the Earth's habitability and health requires serious attention to decisions concerning the production, use, disposal, and destruction of wastes. Among those of particular concern are persistent chemicals that can threaten the health of humans and other species; some of these chemicals are among the most potent toxicants on Earth. Dangers associated with land disposal of such chemicals have stimulated interest in other options, including deep-ocean disposal. Before considering deep-ocean disposal, however, we must first be able to detect the effects that those wastes have on deep-sea life.

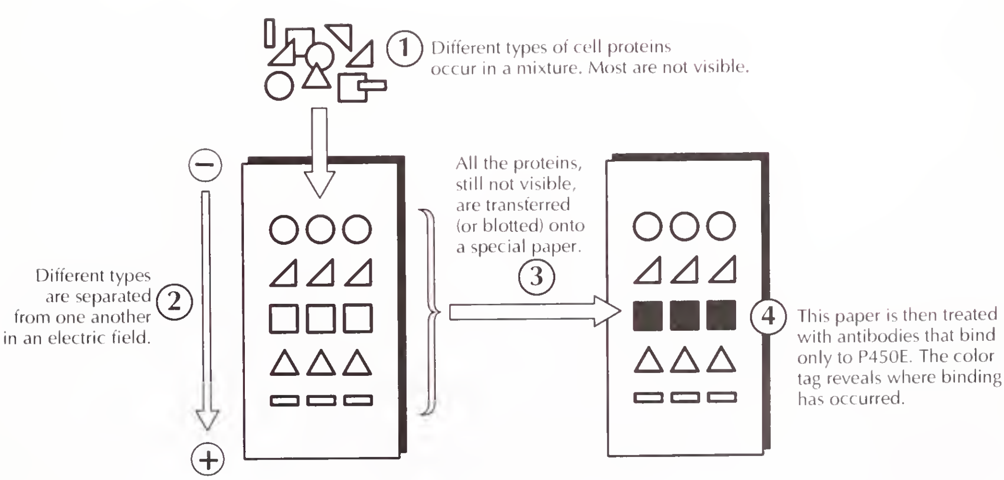
Tools now available to biologists can detect certain biochemical changes, sometimes called "biomarkers," that signal an animal's first response to chemical pollutants. By analyzing biomarkers, we can assess the biological exposure and effects of pollutants more specifically and inexpensively than other methods that assess the presence of the pollutants. Biomarkers have provided the first direct evidence that some chemicals may already be causing biological change in the deep ocean, a region far removed from the known point-sources of those chemicals.

Many of the hazardous chemicals that occur in waste materials are among the families of compounds known as polynuclear aromatic hydrocarbons (PAHs), and chlorinated aromatic hydrocarbons. The latter family includes the subfamilies of polychlorinated biphenyls (PCBs), polychlorinated dibenzofurans (PCDFs), and polychlorinated dioxins (PCDDs). These compounds are fat-soluble and readily taken up by animals; they often concentrate in liver and flesh.

John J. Stegeman is a Senior Scientist and holds the Watson Chair in Biochemistry and Oceanography at the Woods Hole Oceanographic Institution.



Proof that chemical contaminants are causing a biological change in deep-sea fish. Rattail fish (top) were sampled at two deep-sea sites, Carson Canyon off the Newfoundland coast and Hudson Canyon off the New York/New Jersey coast. Protein samples from rattail fish at the two sites were analyzed by the "Western Blot" method (below). The amount of color in the blots (middle) is proportional to the amount of protein that is increased by chemical contamination. Lane 1 sample is from Hudson Canyon, lane 2 sample is from Carson Canyon.



Studies of mammals, and to a lesser extent of fish and birds, show us that PAHs cause cancer and genetic mutations, PCBs promote tumors and affect reproduction, and PCDDs and PCDFs adversely affect immune systems and reproduction. All these compounds also can contribute to the development of cancer.

PAHs and PCBs long have been known as contaminants of ocean waters and sediments, and dioxins and dibenzofurans are now turning up similarly. They all arrive from various sources by a number of routes. The incomplete combustion of material such as wood, paper, and fossil fuels can form PAHs. Dioxins can originate in chlorination processes such as pulp bleaching in the paper industry. PCBs are no longer manufactured but still enter the environment from old sources such as dredged sediments.

Disease in coastal fish as a result of chemical contamination is a matter of serious environmental concern.

Large volumes of sewage effluents containing household and industrial waste carry some of the chemicals into coastal waters, as do rivers bearing waste that was produced inland. These chemicals also enter the sea by way of precipitation from the atmosphere and dumping at coastal and offshore sites, such as the 106 site off New York and New Jersey.

Evidence of disease in coastal fish raises serious concern about chemical effects on the health of the coastal environment. Researchers are finding cancer in bottom-dwelling fish in an increasing number of urban harbors; these cancers are often in the liver and often at high prevalence. This is true along both coasts of North America, in Europe, and even in fish from freshwater sites. We are searching for specific causes of the fish diseases; chemicals are suspected. There also are serious questions about the human health risks, such as cancer, from eating contaminated fish and shellfish. Epidemiological studies already suggest that human health may be affected by the consumption of fish that have high PCB burdens.

Since coastal areas are where both the greatest amount of at-sea waste disposal occurs and the preponderance of marine resources are harvested, this is where the matters of public and environmental health are of most serious concern (see page 39). Contamination of more remote marine regions should be of less immediate concern from a public health perspective. But as many of these chemicals are now present throughout the world's oceans, we can ask whether they might be contributing to biological change in more remote marine systems. If so, are the changes adverse?

We and other researchers are evaluating biomarkers as signals for chemical effects in aquatic species, terrestrial wildlife, and humans. Using biomarkers to investigate the deep-sea environment could provide the essential background information for monitoring the effects of wastes that might be disposed of in the deep ocean.

Establishing cause-and-effect relationships between chemicals and cancer or other health effects is extremely difficult. Field studies usually reveal only casual associations. Laboratory studies linking specific biological changes to specific chemicals require detailed knowledge of the basic biology and biochemistry of the species of concern, and knowledge of the exact processes involved when the chemical in question interacts with living systems. Detailed study of such chemical-biological interactions requires combining analytical chemistry, biochemistry, molecular biology, pathology, physiology, and toxicology—and often draws on such fields as endocrinology and immunology.

Linking chemical causes to environmental effects in the deep ocean is particularly difficult, as the basic biochemistry, physiology, and population biology of deep-sea creatures are even less well known than those of coastal species. Experimental studies on deep-sea species are at best difficult, often impossible, and always costly.

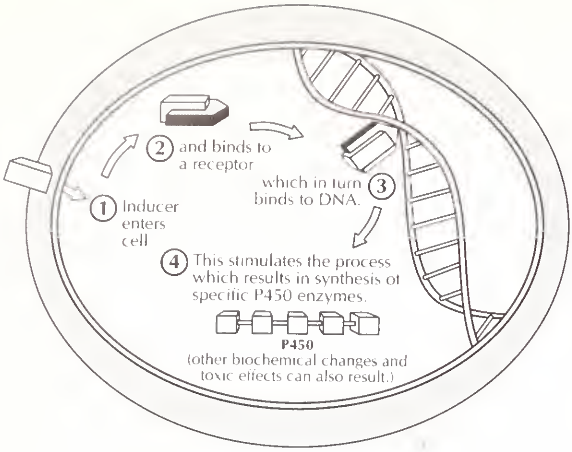
Experiments with deep-sea species are at best difficult, often impossible, and always costly.

Knowing exactly how a specific chemical causes a specific biological change—in other words, knowing a particular biochemical process or mechanism—can facilitate the evaluation of effects in species for which experimentation is not possible. One biochemical process central to the toxicity of many compounds is that by which organisms change the structure of a foreign chemical.

Such structural change can alter the properties of chemicals, and often aids their elimination. This is often an adaptive or protective process, but some products of the structural change can actually be more toxic than the original chemical. In fact, many cancer-causing chemicals become so only after being biochemically converted into products that bind to DNA, resulting in mutations that may lead to cancer.

Enzymes do the work in living cells, including the work of effecting structural changes in foreign chemicals. In a complex process of genetic regulation, called "induction," cells can respond to the presence of foreign chemicals by beginning to synthesize, or synthesizing more of, certain enzymes—enzymes that structurally change chemicals. Specific chemicals, or specific molecular patterns that define families of chemicals, induce the synthesis of a family of enzymes known as the cytochrome P450s. Thus, an increased amount of cytochrome P450 can be used as a biomarker for the presence of a given chemical or chemical family.

Scientists measure the induced amount of an enzyme in several ways. They can measure the rate at which the enzyme does its work; this is called the "activity" of the enzyme. They can measure increased amounts of the enzyme itself, with antibodies that specifically bind to the enzyme. The antibodies can be tagged, and the tags can be developed somewhat like a photographic image is developed—enabling the scientist to "see" the enzyme.



The pathway of P450 induction in mammals. The pathway in fish is similar in most respects.

The activity and antibody detection methods are relatively inexpensive for scientists to perform.

Each of the chemical families and subfamilies that induce P450 synthesis are comprised of many individual compounds, up to more than 200 in the case of PCBs. But laboratory studies show that *the most hazardous* or most toxic members of each group specifically effect the induction. Thus, 3,3′,4,′4′-tetrachlorobiphenyl, 3,3′,4,4′,5′-pentachlorobiphenyl, 2,3,7,8-tetrachlorodibenzodioxin (a PCDD); 2,3,7,8-tetrachlorodibenzofuran (a PCDF); and several such PAHs as the carcinogen benzo[α]pyrene all produce a spectrum of biochemical and toxic effects—of which P450 induction is the most well characterized.

We purified a particular enzyme that we call cytochrome P450E from marine fish. It converts PAHs into mutation-causing products, and these same aromatic hydrocarbons induce the enzyme's synthesis. The highly toxic dioxins, dibenzofurans, and PCBs are also inducers of P450E. This induction is proving to be an early and explicit biomarker of these contaminants.

To make use of P450E as a biomarker we first had to develop:

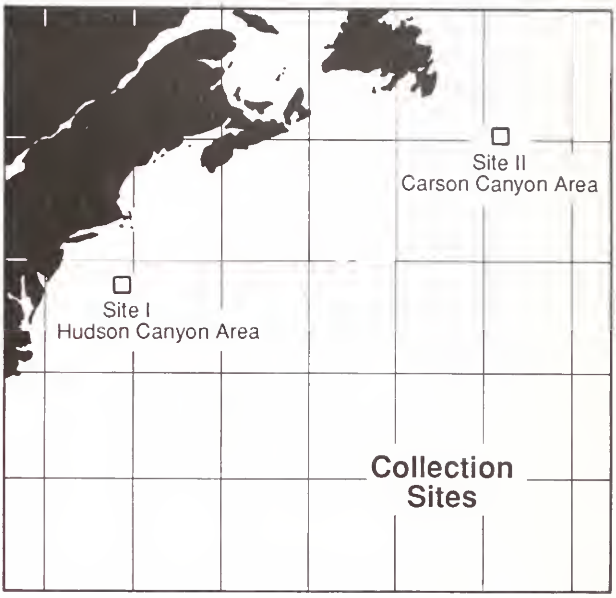
- *a reliable method for purifying the enzyme from fish,*
- *accurate tests of the enzyme's activity, and*
- *antibodies that specifically bind to the enzyme.*

To use the biomarker in deep-sea species, we had to be certain that our capture and retrieval of fish from as deep as 3,000 meters would not alter the biomarker's biochemistry. Specialists in fish taxonomy identified the catch. Organs, usually liver, were removed, flash-frozen in liquid nitrogen, and sent to the laboratory for analysis. Finally, we found that a species of rattail fish, *Coryphaenoides armatus*—widely distributed in the deep sea—was the best candidate.

We subsequently obtained samples of the rattail fish on cruises to two sites about 1,600 kilometers apart in the North Atlantic—Hudson Canyon off the eastern United States, and Carson Canyon off Newfoundland. Using the enzyme activity assay and antibodies to the P450E enzyme, we detected high levels of the biomarker in the southern group's livers, but very low levels in the northern group's livers. Traditional analytical chemistry revealed that the PCB concentrations in the fishes' livers echoed that of the P450E concentrations, with the southern group again having the higher numbers.

The demonstration of P450 induction in deep-sea rattail fish was the first use of antibodies to detect this type of biochemical

change in fish, a change linked to environmental pollutants. The induction indicates that PCBs or other chemicals are present at levels high enough to cause this biochemical effect in animals far removed from known point-sources of the chemicals. While we cannot yet identify the chemical sources, the pollutants could be coming from the Hudson River via the Hudson Canyon trough on the continental slope, or from offshore dumpsites via lateral transport.



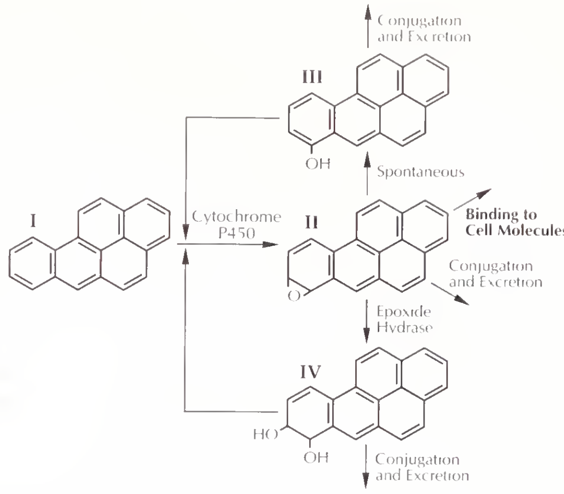
Location of the two sampling sites. The Hudson Canyon area encompasses the 106 site, the Carson Canyon area is far removed from known contaminant sources.

In a more recent collection of the same species of rattail fish near a deep-water (2,500 meters) dumpsite off the U.S. eastern seaboard, we again detected high levels of the chemically inducible cytochrome P450E. Other, subsequent studies of fish in coastal regions of North America and Europe showed a close relationship between the content of the induced enzyme and the content of PCBs and PAHs. We have even seen some P450E induction in whales. Such findings strengthen our interpretation of the results obtained from deep-sea fish.

In the future, biomarkers such as cytochrome P450E could supplant analytical chemistry as a first screen for the presence of many chemical contaminants, including PAHs, PCBs, PCDFs, PCDDs, and possibly others yet unknown. Analytical chemistry, while being the traditional method for identifying chemical contaminants in effluents, marine animal tissues, and sediments, is often very costly and time consuming. Many complex organic molecule mixtures do not even yield to analytical chemistry methods for identification and quantification. The time and cost for biomarker analysis are generally much less than for chemical analysis. Moreover, biomarkers indicate the *biological effect* of chemicals, something not possible with chemical analysis alone.

The induction of P450 enzymes could be a first signal of biological change, one that could be followed by such effects as diseases resulting from the transformation of chemical contaminants into carcinogens. The chemicals that induce biomarker enzymes might also affect the reproduction of coastal and deep-sea life. But linking such biochemical changes as induction to reproduction or other population effects involves an added complexity.

The presence of contaminants in fish, as indicated by P450E induction, presents the threat that these chemicals might return to us in our diet, but the magnitude of this risk is poorly understood. Some scientists believe that most human cancers are preventable,



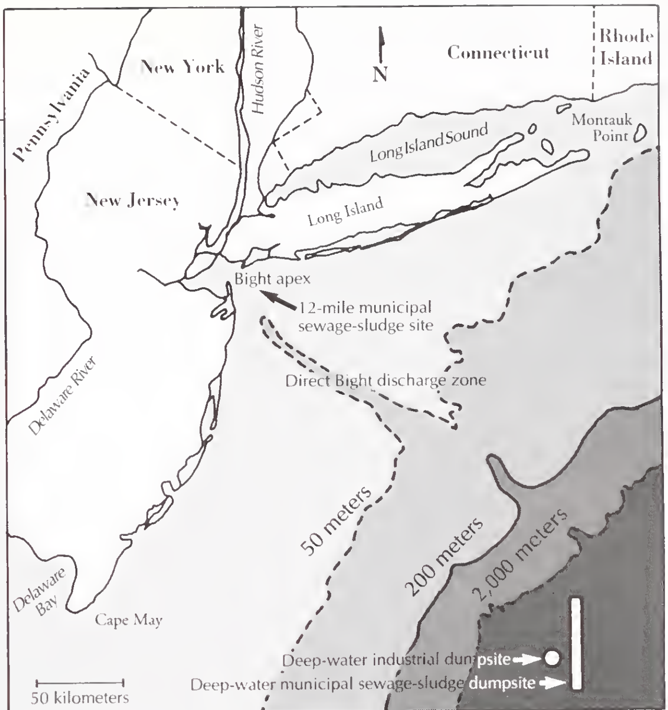
How benzo[α]pyrene is metabolized in fish. Benzo[α]pyrene (I) is converted by cytochrome P450 into product II, which in turn can be converted to products III or IV. These products can be excreted or even acted on again by cytochrome P450.

and associated with factors—such as cigarette smoking—other than chemical pollutants in the environment. By comparison, conferees at a meeting to discuss cancer risk associated with contaminated seafood concluded that although the risk is real, the added number of cancers would likely be small, and very difficult to define. Food fish are not taken from the very deep ocean, presumably reducing this problem for deep-ocean disposal.

Debate concerning waste disposal in the oceans must consider not only the potential hazards, but also the means to monitor disposal sites for chemically induced biological change. As described here, a critical element in judging the chemical hazard to living systems is the ability to detect and evaluate both exposure and effects. Biomarkers for chemical exposure and effect—such as cytochrome P450E, specific DNA damage, and others—will be an essential component of such monitoring.

Many U.S. waste-disposal practices should not continue. Without change, some coastal regions would soon become fit for little other than waste disposal. In such regions, no resources could be taken, or even expected. Whether society might accept adverse changes in deep-sea animal health in lieu of greater potential for adverse human health effects from land-based and coastal ocean disposal is a matter for serious discussion.

In the realm of chemical effects in the environment, it is often a long, arduous process to reach the point of being able to say "I know" instead of "I suspect." If we are to approach the question of waste disposal and its consequences from a rational standpoint, then it is essential that we continue vigorous, basic research on mechanisms of toxicity in both animals and humans. It is only through such research that we will understand the consequences of waste disposal, and attain the means to monitor and/or counter these effects.



Sludge Reaching Bottom at the 106 Site, Not Dispersing as Plan Predicted

By June 30, 1992, when New York City plans to end ocean dumping, more than 25 million wet tonnes of sewage sludge will have been dumped at the 106 site about 160 kilometers off the coast of New Jersey in waters more than 2.4 kilometers deep. Although disposal of massive quantities of wastes in nearshore, relatively shallow environments is not unusual, this sludge disposal is the largest manmade perturbation of a deep-ocean environment.

In September, 1989, a multidisciplinary research team visited the site with the deep-diving submersible* DSV/Alvin. *Some 7.25 million tonnes of sludge had already been dumped when the team made their visit, the purpose of which was to verify a computer model of the sludge sinking to the bottom and determine what biological effects it might have if it was reaching the bottom.*

According to the Environmental Protection Agency's Monitoring Plan, 1988, the sludge was supposed to have totally dispersed during its descent from the surface, with none detectable on the bottom. Our model took into account new information on currents and sludge particle size and fall velocity, and predicted that measurable amounts of sludge would reach the bottom.

We had support from the National Oceanic and Atmospheric Administration's National Undersea Research Program for 10

days' use of the R/V Atlantis II *and* Alvin, *as well as support for seabed sample analyses. Ginger Fry and Brad Butman of the U.S. Geological Survey (USGS) in Woods Hole developed a model that calculated a contour plot of sludge concentrations on a theoretically flat seafloor over distances as far as 250 kilometers from the site and guided our sampling strategy. Studies of near-bottom currents will allow more sophisticated models to be developed.*

We knew the bottom was not flat even though the area was below the more rugged terrain of the continental slope. Joyce Miller of the University of Rhode Island Seabeam group helped us produce a contour chart of an area of about 1,350 square kilometers, including about 210 square kilometers of the site. The chart's 10-meter depth contours identified several depressions that might trap particles settling from the surface. Alvin's *manipulator carefully sampled the upper sediments in those depressions, and outside the depressions for comparison.*

Animals living on the bottom near the 106 site are typical deep-sea creatures, such as starfish, shrimp, sea urchins, and sea cucumbers.

Samples are still being analyzed by the research team. But from levels of trace metals found by Mike Bothner of the USGS, bacterial spores of Clostridium perfringens*—a human sewage indicator—found by Ivor Knight and Rita Colwell of the University of Maryland, and stable isotope ratios found in the animals living in the sediment by Cindy Van Dover of Woods Hole Oceanographic Institution, we can definitely say that measurable amounts of sludge are reaching the bottom immediately to the west of the site, as predicted by the model.*

This project should help us to better understand how the sludge is transported, and to learn whether the rich variety of deep-sea species is influenced by the sewage sludge input.

—Frederick Grassle
Project Coordinator
Rutgers University

** In addition to those mentioned, team members were: Rosemarie Petrecca, Rutgers University; James Robb, Branch of Atlantic Marine Geology of the USGS; Michael Moore, John Stegeman, and John Farrington, Woods Hole Oceanographic Institution; and Robert Whitlach, University of Connecticut.*

Managing Dredged Materials

The U.S. Army Corps of Engineers regulates dredging from waterways throughout the country.

by Robert M. Engler

Navigable waterways and their role in transportation and defense are vital components of the economic growth and stability of coastal nations. However, most near-shore and estuarine areas are naturally shallow. Depths that support modern shipping are maintained only by dredging, which removes sediment and aquatic soil that naturally accumulate in navigation channels.

Annually, hundreds of millions of cubic meters of dredged material are brought up from the world's harbors, and it must be placed and managed in an economically and ecologically sound manner. Since the annual cost of port and waterway maintenance worldwide ranges in the hundreds of millions of dollars, officials seek the least costly, environmentally sound methods of dredged-material transport and placement—either on land, at sea, or at another estuarine location.

Dredged material is a mixture of sand, silt, and clay. It can include rock, gravel, organic matter, and contaminants from a wide range of agricultural, urban, and industrial sources. If it were not for those contaminants, dredged sediments would consist only of natural components of the Earth's crust deposited by natural erosional and mineralization processes. Contaminated or otherwise unacceptable dredged material accounts for only a small fraction of the total—less than 10 percent in the U.S. and globally.

Uncontaminated, or "clean" dredged material may be placed at the broadest range of locations with environmental concern limited only to physical impacts, the most significant of which is habitat modification in the aquatic environment. Clean material has many positive uses. These include the development and enhancement of wetlands, and aquatic and wildlife habitat; beach nourishment;

land development; offshore mound and island construction; agriculture; mariculture; and construction aggregate. The benefits of such positive uses are significant and should receive highest priority in a dredged-material management policy. An increase in the positive use of dredged material would signal a decrease in the use of disposal sites.

In industrialized harbors, typical contaminants are toxic metals, organohalogens like PCBs, petrochemical by-products, excess nutrients, and harmful microbes. As many waterways are located in industrialized areas, the disposal of contaminated sediments generates serious environmental concerns.

Regulatory controls in the United States are developed by the U.S. Environmental Protection Agency (EPA) through the authority of the Marine Protection Research and Sanctuaries Act of 1972. This act authorizes the U.S. Army Corps of Engineers to issue permits for the ocean placement of dredged material, and apply the EPA's controls. Internationally, the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, often called the London Dumping Convention (LDC, see page 29) regulates ocean placement of dredged material. In 1986, the convention agreed on special guidelines for the management of such placement.

Dredges sometimes empty material directly onto barges, which transport the material elsewhere.

The LDC guidelines separate the regulation and assessment of dredged material from that of other wastes, and require alternatives to ocean placement to be reviewed. The alternatives are assessed on the basis of such human-health and environmental concerns as safety, economics, and the possible exclusion of future uses for disposal areas. Furthermore, the guidelines recognize that "Sea disposal [of dredged material] is often an acceptable disposal option," and encourage positive uses. The LDC's approach and the EPA's regulations are fully compatible.

Procedures for assessing dredged material include:

- *analyzing toxicological characteristics,*
- *analyzing proposed placement site characteristics,*
- *reviewing placement methods, and*
- *considering alternate placement sites.*

The beach, at right, consists of sand dredged from the West Pearl River, Louisiana. Originally built in the 1950s, the beach's size and condition are maintained by periodic additions of sand. Below: the only nesting colony of brown pelicans in Alabama breeds on Galliard Island, made entirely from dredged materials.

Dredged materials can provide agricultural land for crops such as these cabbages along the Washington side of Columbia River.

The EPA and Corps of Engineers classify dredged material using the results of tests that determine the presence of specific contaminants, their bulk toxicity, leachability, and biological availability. Sediments that have toxic and biologically available contaminants are banned from ocean placement. The tests range from simple water leaches to multiorganism benthic bioassays.

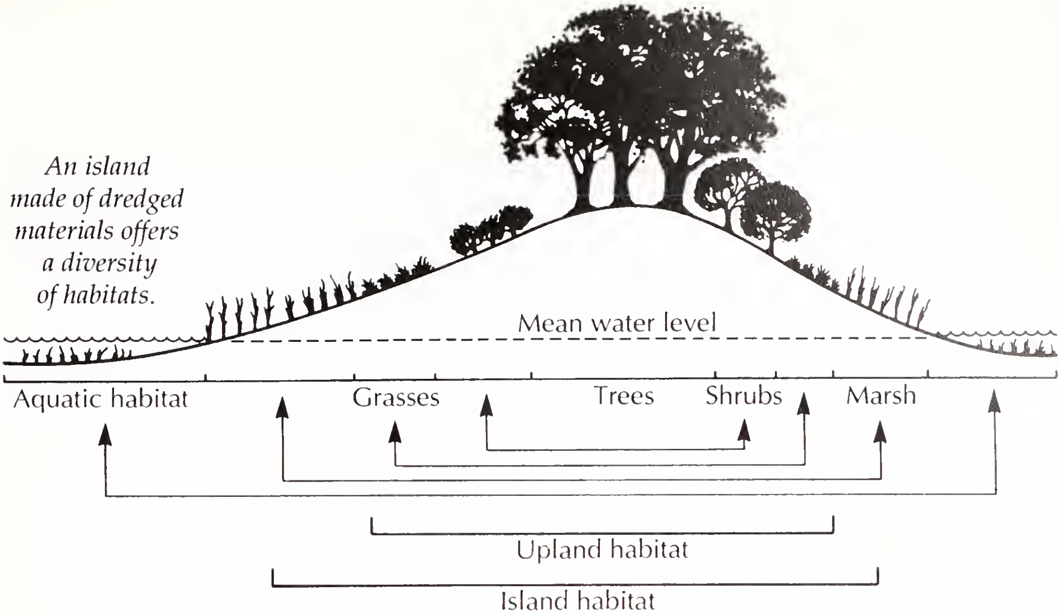
Placement-site characteristics include topography, and proximity to recreation areas, fisheries, waterways, and sensitive marine-resource areas. Proposed sites also must be amenable to monitoring and management.

When dredged material is deposited at a placement site, the release of contaminants from it may be drastically enhanced or retarded, depending on how the water-sediment geochemical environment is changed. For example, a significant release of such metals as zinc can occur under acidic oxidizing conditions, which do not normally occur in aquatic placement. Laboratory studies simulating upland placement where drying and oxidation can occur show that dredged material so placed can become acidic. Upland placement of marine sediments with a high level of sulfide led, after several months of drying and oxidation, to acid conditions and subsequent metal leaching.

Suction dredges clear out channels by redistributing sediments.

Laboratory research also indicates, however, that there is minor release of most manmade chemicals from dredged material because they bind so tightly to clay and organic matter.

Sediment-bound contaminants emphasize the need for determining the biological effects of the solid fraction. The solid phase of dredged material rapidly settles to the bottom and has intimate association with the benthic, or bottom-dwelling, organisms. Sediment-bound contaminants may be made available to aquatic biota through ingestion or direct contact by the organism or, on the other hand, buried at the placement site with clean sediment effectively isolating them from marine organisms. Regardless of the chemical nature of the solid phase, the physical effects on various organisms also must be thoroughly evaluated.



Investigations have been carried out to determine the effects of suspended dredged material on aquatic organisms, the ability of organisms to migrate vertically through deposits of settled material, and the bioaccumulation of sediment-bound contaminants. The ecological effects of sediments contaminated with a wide range of pollutants continue to be investigated by various organizations in countries around the world. Results of these investigations form the basis for the management of dredged material placement.

The short-term and long-term chemical, physical, and biological impacts of open-water placement have been determined by large investigations in numerous locations. The locations were largely regarded as nondispersive or low-energy environments with regard to sediment resuspension or transport. Chemical effects in the water column duplicated the laboratory test results previously reported.

When material was placed in a nondispersive aquatic site, movement or release of the chemical constituents in relation to reference sites was not apparent. Suspended particulate concentrations were less than concentrations that have been established to have an impact on a broad range of aquatic organisms. These low concentrations persisted only for a few hours.

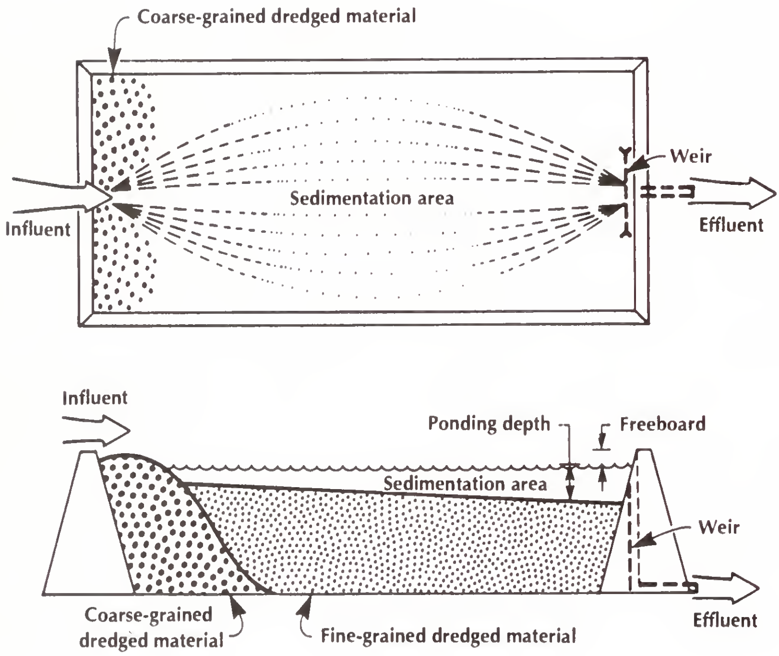
A significant impact is the formation of mounds of dredged material at aquatic placement sites. Biological recolonization of these mounds demonstrates that conditions eventually return to the original state. Biological recolonization is rapid on fine-grained sediment, while sandy substrates exhibited slower recovery. Sites that receive multiple placements continue to reflect physical impacts and must be carefully chosen to minimize damage to important amenities of the marine environment.

The sediment characteristics that most affect the mobility and biological availability of dredged materials are particle size, organic matter content, amount and type of ions, amount of iron and

manganese, oxidation/reduction potential, pH, and salinity.

When the physical-chemical environment of a contaminated sediment is altered by removal and placement, the chemical and biological processes important to mobilization or immobilization of potentially toxic materials may be affected. Frequently, an altered physical-chemical environment that results in the release of contaminants from one chemical form will favor other immobilizing reactions. As an example, aquatic placement under reducing, neutral pH conditions will favor immobilization of toxic metals while having little effect on mobility of organohalogens. The influence of physical-chemical conditions associated with various placement methods on the release of contaminants must be identified.

In addition to the chemical properties of the contaminant, the chemical and physical properties of the dredged material will influence the mobility of contaminants at relocation sites. A number of readily identified properties of dredged material affect the mobility and biological availability of various contaminants. Some of these properties can change when the material is moved from one type of disposal environment to another; whereas other properties are not affected by changes in water content, aeration, or salinity.



Dredged material is de-watered in special containment areas as shown above.

Much of the dredged material removed during harbor and channel maintenance dredging contains a high proportion of organic matter and clay and is biologically and chemically active. It is usually devoid of oxygen and may contain an appreciable amount of sulfide.

These conditions favor effective immobilization of many contaminants provided the dredged material is not subject to mixing, resuspension, and transport induced by waves or currents. Coarse-textured sediments that have a low organic matter content are much less effective in immobilizing metal and organic contaminants.

These materials do not tend to accumulate contaminants unless a contamination source is nearby. Should sediment contamination exist, then potentially toxic substances may be released to the water column or leaching and uptake of contaminants by plants may occur under intertidal or land placement conditions.

Many contaminated sediments are initially anoxic and have a near-neutral pH. Subaqueous disposal into quiescent waters will generally maintain these conditions and favor immobilization of contaminants. By contrast, certain noncalcareous sediments contain appreciable reactive iron and particularly reduced sulfur compounds. These sediments may become moderately to strongly acid upon gradual drainage and subsequent oxidation, as may occur when upland disposal takes place. This offers a high potential for mobilizing potentially toxic metals.

For sediments that have been determined to represent a high environmental risk, placement methods favoring containment of potentially toxic substances should be considered.

Many contaminated sediments are initially anoxic and have a near-neutral pH.

Many examples demonstrate that highly contaminated dredged material can be managed in ocean locations if sufficient care is exercised with site selection to ensure that the material is isolated from the biotic zone of the marine system. This approach can involve site management techniques such as covering with clean sediment, or locating sites in abiotic areas. The available scientific and engineering data indicate that, for the greater part, dredged material should be regarded as a highly manageable resource for productive use in the marine environment.

No simple solution to the placement of contaminated dredged material exists, but with proper management, the aquatic environment can offer a logical and environmentally sound alternative to land-based sites. The approach of carefully managing open-water sites should be considered a primary management solution to a perplexing problem. The same degree of waste management should also be strictly applied to land containment or inland disposal of dredged material. The majority of sediments dredged from the coastal zone can be used for a wide range of productive and beneficial uses that should be a high priority in the selection of placement alternatives.

Robert M. Engler is Manager of the Environmental Effects of Dredging Programs in the Environmental Laboratory of the U.S. Army Corps of Engineers Waterways Experiment Station in Vicksburg, Virginia. Since 1977, he has served as a U.S. State Department representative at the annual meetings of the London Dumping Convention's Consultative and Scientific Group on Dumping, and since 1988 has been Chairman of the group.

Tailoring Waste Disposal to Economic Realities

The economics of waste disposal is a special case of transportation economics. In transportation economics, the problem is to move a commodity from a place where it has a lower value to a place where it has a higher value without spending more on transportation than the difference in the commodity's value between locations. The big distinction for waste disposal is that the "commodity" (waste) typically has cost, or negative value, at both locations: a large negative value at its point of origin and presumably a smaller negative value at its disposal site.

If, for equivalent benefits, transportation costs to ocean sites are lower than to onshore disposal sites, then ocean disposal would be preferred. Significantly lower transportation costs do in fact appear to explain those cases where ocean disposal has been chosen over onshore disposal. The real problem arises in measuring the benefits gained. Waste-disposal benefits occur mainly as reduced environmental costs, such as reduced risk to human health, less damage to living resources, fewer insults to aesthetic and recreational amenities, and so on.

Largely because of scientific unknowns, but in part because of limitations in economic technique, such environmental benefits and costs have not been readily measurable for ocean disposal. However, indirect inferences about their relative magnitudes may be attempted by using direct measures of transportation costs, which comprise packaging, handling, and hauling costs.

Thomas Leschine of the University of Washington and I, for example, estimated in 1985 that the cost of transporting sewage sludge from the New York City region to the deepwater dumpsite 106 miles offshore was four times larger than the cost of transporting it to the existing dumpsite 12 miles offshore. Still, New York area disposal authorities were required to move to the 106 site, implying that environmental costs to society at the 12-mile site were judged to be much larger than—at least triple—those incurred by disposal at the more distant deepwater site.

Last year, after New York City invested tens of millions of dollars in new barges to use the deeper site, Congress outlawed ocean dumping altogether. This, in turn, implies that the net environmental benefits gained from the greater onshore disposal costs must exceed even those available from hauling the sludge 106 miles offshore. Notwithstanding the legislation, scientific and economic results demonstrating this advantage have not been forthcoming.

A somewhat less abstract facet of the ocean waste-disposal issue is a widespread perception of underworld involvement. Leschine and I gathered indirect evidence on this question, too. One New York company that concentrated its investments in off-Broadway shows and toxic waste disposal was promoting a scheme to transport toxic-laden New York sludge in surplus tankers to the Caribbean as fertilizer spray for banana plantations.

To the CEO of this company, I mentioned the name of my upcoming interview at another waste disposal firm in New Jersey. "Sure, I know him," said the New York exec. "My uncle used to work for his family."

"Is that so?" I dutifully pursued.

"Yeah," he continued, "my uncle was a tailor. . . . He worked in cement."

—James M. Broadus
Director, Marine Policy Center
Woods Hole Oceanographic Institution

Herculean Labors to Clean Wastewater

by T. M. Hawley

According to mythology, when Hercules arrived at the stables of King Augeas, 30 years' worth of muck from the king's 3,000 cattle had accumulated. As one of his 12 Labors, Hercules was under orders to clean the stables in one day. Since one cow produces roughly 18 wet tonnes of waste in a year, he had about 1.6 million wet tonnes to get rid of. That's nearly the amount of sewage sludge that New York City disposes of at the 106 site every four months, according to U.S. Environmental Protection Agency estimates.

Hercules cleaned the stables by a disarmingly simple method: He rerouted two rivers so they would flow through the stables and flush the filth into an estuary. His ecological conscience was strong enough to urge him to put the rivers back in their normal courses before nightfall, but it seems he never gave a thought to the environmental impact his feat was having downstream.

The sheer volume of this tsunami of sewage could have filled a huge expanse of wetlands and buried sediment-dwelling plants and animals living far offshore. The nutrient load would have set off a meteoric and far-flung algal bloom and catastrophic drop in dissolved oxygen. Had such a civil engineering project actually ever been carried out in ancient times, we might still be able to see traces of its effects in sediment cores today.

The image of clean water sweeping sewage away downstream is a strong one—meaningful to the ancient Greeks and still repeated every day in toilets around the world. But wastewater is more than simply solids fouling a stream of clean water. It is a river of biological potential that is only partially addressed in the standard "primary" and "secondary" treatment technologies (see diagram, page 32). Although these technologies effectively separate solid wastes from the water that carried them out of our homes, they produce considerable amounts of sludge in the process, and usually fail to remove many inorganic nutrients that dissolve in the water along the way. Those nutrients—nitrate, phosphate, and others—must be removed if the water is to have a minimal impact on the environment. And then there is the sludge: It cannot be dumped in U.S. waters after 1991, and fewer communities are

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willing to allow their landfills to harbor the material.

Increasingly, excess nutrients in the world's coastal waters trigger red tides and eutrophication, scientists say. In 1988, a bloom of *Ptychodiscus brevis*, a type of phytoplankton normally restricted to the Florida Gulf Coast, devastated the dolphin population as far north as New Jersey. The phytoplankton's spread to the Atlantic may have been assisted by excess nutrients there. In and around the Baltic Sea, effects of eutrophication—benthic depletion of oxygen and loss of species diversity, and increased frequency and range of algal blooms and turbidity—have been linked to excess nutrients introduced by human activities.

Less nitrogen and phosphorus in effluents discharged into coastal waters would likely reduce the occurrence and range of red tides.

The success of sewage treatment is usually gauged by comparing certain quantities in the "influent," or wastewater flowing into a sewage treatment plant, to those in the "effluent," or treated water discharged to the environment; typical successes are listed in the table below. The essential difference between primary and secondary treatment is that primary treatment uses mainly gravity to remove solid material, whereas secondary treatment combines biology with gravity. The biology comes in the form of microorganisms that eat particles too small to settle out during primary treatment. The particles thus are transformed into living material, which, after it dies, sinks in secondary settling tanks. Both primary and secondary treatment produce sludge, or the solid material removed during treatment. Secondary treatment, not surprisingly, produces nearly twice as much sludge as does primary.

In the face of coastal eutrophication and diminishing sludge disposal options, alternative sewage treatment technologies are becoming more attractive. These systems usually address either sewage's biological potential more directly than standard treatment does, or technologically lower sludge production. Whatever the treatment method, the objectives are to discharge effluent that is

What's Left After Sewage Treatment

		Typical percent removal	
		Primary treatment	Secondary treatment
Biological Oxygen Demand (BOD)	The amount of dissolved oxygen necessary for the aerobic decompsition of organic matter in water.	35	85
Nitrogen	Becomes a nutrient, when combined with hydrogen or oxygen to form ammonia, nitrate, or nitrite.	15 to 20	30
Phosphorus	Becomes a nutrient, when combined with oxygen to form phosphate.	15 to 20	30
Suspended solids	Undissolved material suspended in water.	60	85

cleaner than the waters receiving it, keep sludge to a minimum, and dispose of sludge in an environmentally responsible manner.

A system called "advanced primary" treatment adds synthetic polymers and ferric chloride to wastewater early in the treatment process, which cause suspended solids in primary settling tanks to coagulate and sink. In advanced primary treatment, Biological Oxygen Demand (BOD) removal and sludge production is about midway between primary and secondary treatment, and suspended solids removal is about equal to secondary treatment. An advocate of advanced primary treatment, Massachusetts Institute of Technology Professor of Civil Engineering Donald R. F. Harleman, says that in Scandinavia this system removes 95 percent of the nitrogen and about 30 percent of the phosphorus entering it.

In Florida, the Iron Bridge treatment plant serves part of Orlando and a few nearby communities, the fourth-fastest-growing metropolitan area in the United States. In 1984, the plant had almost reached its design capacity of 24 million gallons a day, and the communities faced building moratoriums unless capacity could be significantly increased and effluent disposed of acceptably. The solution was found in using reclaimed and natural wetlands to "polish" the effluent prior to its discharge into the St. Johns River.

What is now known as the Orlando Easterly Wetlands Reclamation Project was constructed on a previously drained wetlands, and encompasses a 6.6-square kilometer wilderness park.

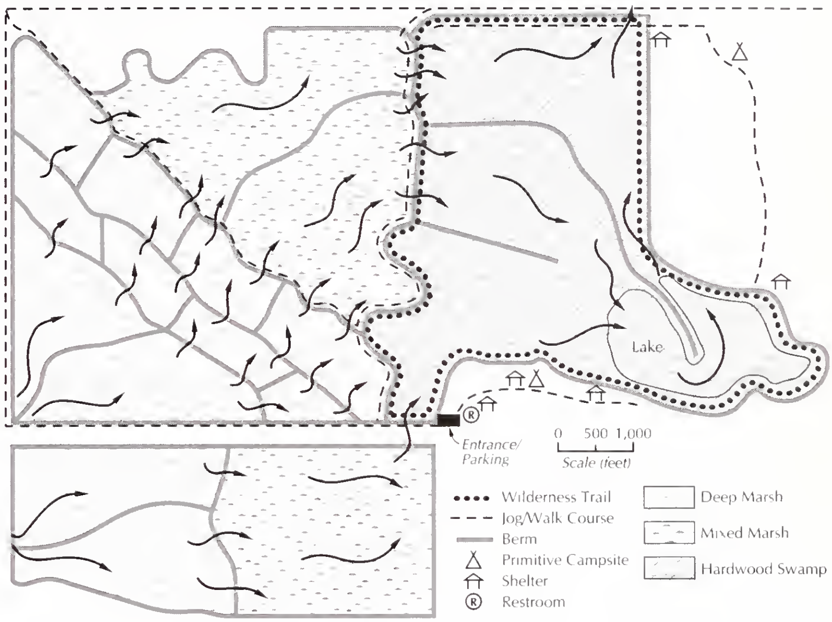
Already clean to secondary standards, effluent from Iron Bridge flows through the reclaimed wetlands that consist of three plant communities—deep marsh, mixed marsh, and hardwood swamp. In 1989, this system removed 80 to 90 percent of the total nitrogen and phosphorus from the water flowing through it. The wetlands are cellularized by an array of earthwork berms, or dikes, that allow for precise flow control and monitoring, and any maintenance or harvesting that might be necessary.

After filtering through the reclaimed wetlands, the Iron Bridge effluent then passes through a natural wetlands before final discharge to the St. Johns River. An environmentalist group, however, first protested that a continuous flow of highly treated effluent would adversely change the character of the natural wetlands. The group, the Nature Conservancy, previously owned the natural wetlands, and stipulated during the change of ownership to the St. Johns River Water Management District that the natural wetlands' character was not to change. Eventually the two parties struck an agreement to closely monitor changes in the natural wetlands, and to mitigate specified detrimental changes should they occur.

In other places with long growing seasons, other wetlands have been engineered to polish sewage-plant effluents. These projects range from the relatively natural conditions of Orlando's system to "rock marshes"—fields of small rocks that have effluent flowing beneath the surface, and such plants as water iris or canna lilies growing up through them.

Artificial wetlands are cleaning wastewater even in New England, despite its short growing season. One system is called "Solar Aquatics." It treats either raw sewage or septage, rather than the effluent of a conventional treatment plant. In the confines of a greenhouse, a series of 5,000-liter clear plastic silos are home to engineered ecosystems that progressively convert the wastewater's organic matter and inoganic nutrients into bacteria; phyto- and zooplankton; algae; higher plants such as duckweed and bulrushes; snails; and fish.

Orlando Easterly Wetlands Reclamation Project and Wilderness Park



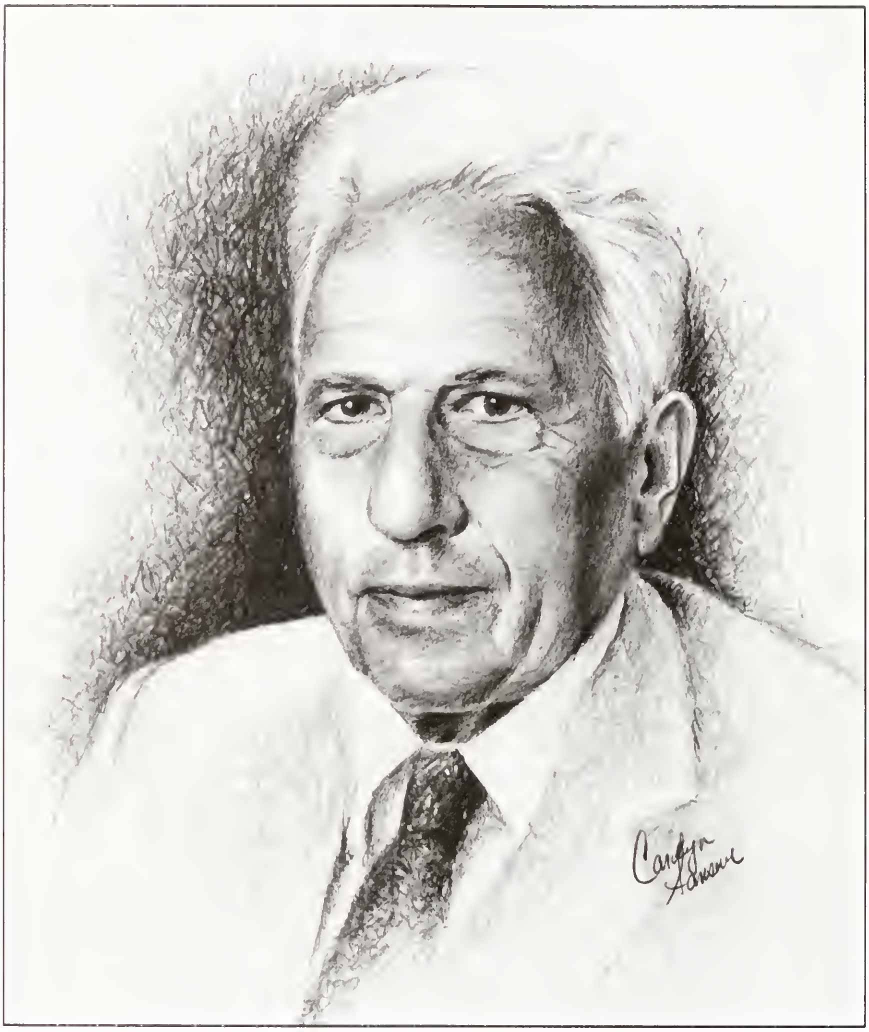
In Providence, Rhode Island, a Solar Aquatics system treats nearly 60,000 liters a day of domestic sewage laced with metals such as copper, zinc, and cadmium. About every two weeks, half the floating vegetation in the system is harvested, shredded, and composted. An average harvest is about 160 wet kilograms. This is the system's "sludge." Removal of BOD, suspended solids, and ammonia runs between 90 and 98 percent.

Material harvested from the Providence plant has yet to be completely composted, but when it is, it will be tested for the presence of metals and synthetic chemicals. If the concentration of these contaminants is low enough for safe application in horticultural settings, it will be used for this purpose. If the levels are too high, Solar Aquatics developers say that the compost can be put back into the system, and the toxic materials can be taken up by tree seedlings. In trees, these contaminants will be effectively sequestered from the human environment for the life of the trees.

Although these various innovative technologies are promising, some large U.S. cities have a long way to go before achieving environmentally friendly sewage treatment and sludge disposal. While Chicago and Milwaukee package and market their sludge as fertilizer for golf courses, in Boston and elsewhere, combined storm and domestic sewage outfalls produce the same effect as Hercules's labor at the Augean stables. Source reduction is virtually unheard of in the context of domestic wastewater. Yet how many tonnes of compostable material pass through garbage disposals and into the sewers of the United States each year?

two profiles:

The Profane



Edward D. Goldberg

by Joseph E. Brown

Just past his second-story office window in Ritter Hall, the Pacific Ocean laps gently on the shore. It's a gorgeous, made-in-California morning, perfect for relaxation and distraction. But Edward D. Goldberg seems not to notice the temptations beyond his window.

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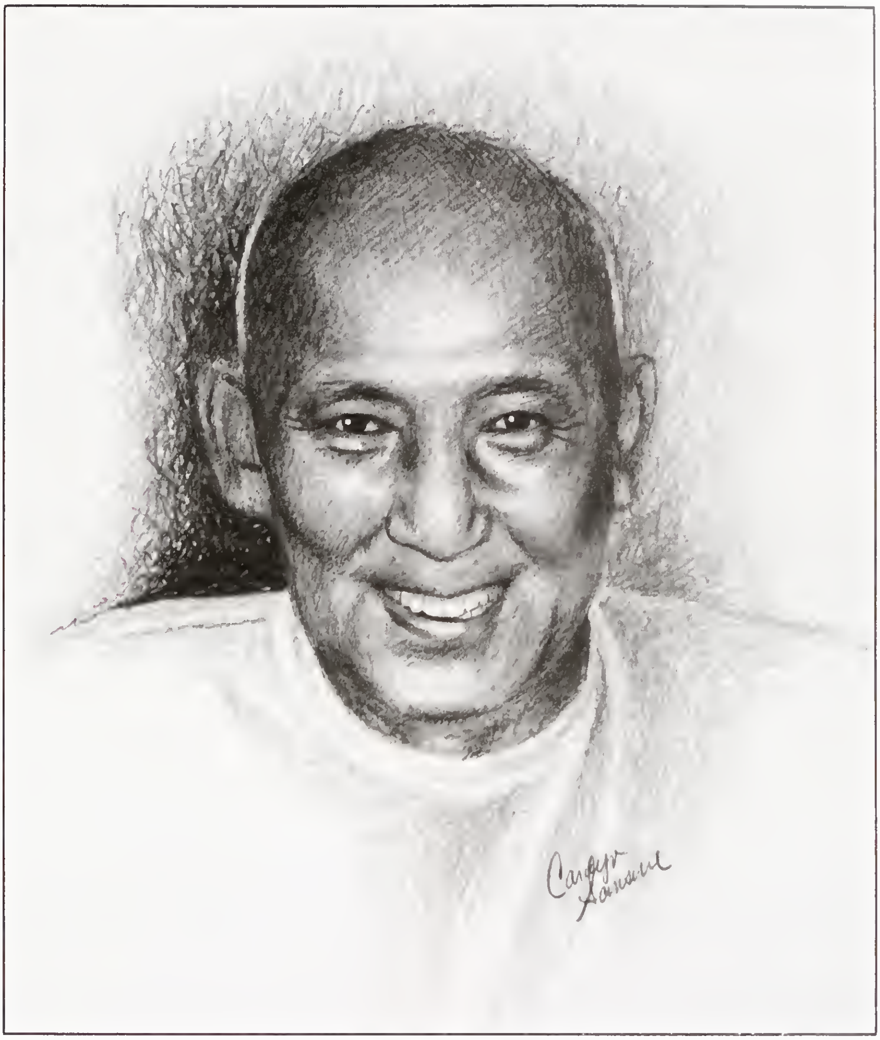
The Poet



Paul Kilho Park

by Michael A. Champ

In 1931, in Kobe, Japan, the 63d descendant of a Korean King was born. His pursuit of knowledge, understanding, and wisdom would carry him throughout the world and make him one of the leading authorities on the disposal of wastes in the ocean.

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As on most mornings, Goldberg is already a half-hour into his daily work at 7:30 A.M., scrunched down in his swivel chair next to a word processor just below a bookshelf lined with a red-bound, multivolume set of *Analytical Chemistry*.

All told, Goldberg has been on the payroll of Scripps Institution of Oceanography at the University of California at San Diego for 41 years, the last 31 of which have been as a professor of chemistry. In fact, except for a brief stint in the Navy during World War II, it's the only job he's ever known.

"Thanks to Dr. Goldberg," said a University of Southern California spokesman last year while awarding him the prestigious Tyler Prize for Environmental Achievement, "scientists and policymakers now have an increased knowledge of the contamination levels of coastal waters in most parts of the world. And the pollution measurements in different laboratories are being made on a comparable basis."

R. B. Clarke, Professor of Zoology at the University of Newcastle-Upon-Tyne, England, describes Goldberg as "the doyen of marine environmentalists." To John W. Farrington, former Professor of Environmental Sciences at the University of Massachusetts and now Dean of Education at the Woods Hole Oceanographic Institution (WHOI), he's "the most innovative, influential scholar to ponder, investigate, write, and speak about ocean pollution problems."

Goldberg has written 225 articles and two books on marine chemistry and human impact on the oceans *(The Health of the Oceans* and *Black Carbon in the Environment).* He presently serves on editorial boards of four scientific journals, and was for a long time on the board of this magazine. He has been a tireless organizer of workshops, seminars, and conferences on ocean subjects. "Ask Ed for help," a colleague notes, "and he'll come running at the drop of a petri dish." Awards and guest lectureships take pages to list.

When not head-down in his office in La Jolla, chances are he is off wandering the globe in such diverse places as Switzerland (studying the rates of accumulation of glaciers), Belgium (investigating pollution in the North Sea), Yugoslavia (discussing Mediterranean chemistry), or Scotland (more North Sea science).

Edward David Goldberg was born in Sacramento, California. Although his father, a high-school teacher, died when Goldberg was very young, his mother, a piano teacher, lived to age 90. "My mother's longevity," he remembers with a wry smile, "gives me a sense of how long I might live if I hadn't smoked as long as I did."

Goldberg received a degree in chemistry from the University of California at Berkeley in 1942. He served as a naval officer in the South Pacific during World War II, "helping to demagnetize ships. I was totally bored . . . if you *can* be bored in the middle of a war."

After the war, he began his postgraduate studies at the University of Chicago. As one historian described it, the university at that time was "a hothouse environment" of science—possibly the greatest concentration of talent in the field of geochemistry in the entire world.

Goldberg's personal mentor was Harrison Brown, a brilliant geochemist whose research reached into outer space; he was, among other things, the codiscoverer of methods to determine the age of meteorites and the Earth. Goldberg wrote his first five papers in collaboration with Brown; they dealt with the minor metallic components of iron meteorites—nickel, cobalt, gallium, rhenium, palladium, and gold.

Brown was obviously impressed with his budding protégé. On the telephone one day in 1949, he men-

(continued on page 80)

At the age of 14 in Japan, Paul Kilho Park was selected by the military to receive kamikaze pilot training. He passed the rigorous physical and psychological tests just as World War II was ending, but never received flight training. He returned to Korea after the war, where he earned a degree from the National Fisheries College in Busan (now Pusan) in 1953.

During the Korean War, Park met two Texas cowboys whose "can do" attitude impressed him. He decided to go to Texas A&M University to further his education. He wrote Dale F. Leipper, Chairman of the Oceanography Department, that he was coming. Having learned English from his Texas friends and a dictionary, Park arrived at College Station, Texas, and soon became a chemical oceanographer. By the time he received his M.S. in oceanography in 1957, he had become very interested in the carbon dioxide system in seawater.

He next decided to go to the California Institute of Technology for a Ph.D. So he bought a Nash Rambler, and departed College Station. At Cal Tech, he found Professor Samuel Epstein's office and knocked on the door, introduced himself, and said: "I have come to be your student." The flabbergasted Epstein told Kilho to first submit an application, and sent him back to Texas A&M. In later years, Epstein would offer Park a postdoctoral fellowship, without having applied. On his return to Texas, Park re-enrolled. He received his doctorate in oceanography, with emphasis in chemistry, in 1961.

The Teacher

From 1961 to 1976, Kilho was a faculty member at Oregon State University, becoming a professor of oceanography in 1971. Park is considered by many of his Oregon State students to be one of the most memorable in their academic careers, citing him especially as a source of inspiration and applauding his drive for knowledge.

Park was extremely hard on students. First, he was completely unambiguous about his course being the most important that they were taking. (If you don't believe that, just ask him.) Second, they had to learn everything in it. For Kilho, it was not sufficient to be able to line up causes with effects; students had to know the process and be able to prove it at the blackboard. Also, they had to defend two or more sides of an issue, even if it was the short side. Kilho's students had to be familiar with at least one analytical method for each element in the periodic chart.

Professor Park always handed out lecture notes. He earned a reputation for wearing out many copy machines, because the notes were so comprehensive. Many of his former students still have these lecture notes some 20 or more years later. Larry Swanson of the State University of New York at Stony Brook once had to go on a cruise in the middle of Park's classes and had his wife Dana sit in on the class and take notes for fear of missing a word.

Park has always encouraged graduate students, young scientists, and professors to continue to pursue their research and interests in the face of adversity. In later years, while visiting different campuses to review research results with principal investigators, he made it a point to meet with the students and to give a seminar. He has always strived to be at the cutting edge of research and knows that one must constantly push to find or stay at that edge. He believes firmly in the development of a hypothesis, its subsequent testing, and the iteration process to revise the hypothesis.

The Scientist

As a chemical oceanographer, Kilho was highly productive during the 1960s through the '70s, spending long periods at sea making scientific contributions in the areas of nutrient relationships and

(continued on page 81)

tioned to Roger Revelle, then Director of Scripps and interested in new scientific talent, that Goldberg was about to complete his Ph.D. in chemistry. "Scripps was rather short of chemists at the time," Revelle recalls, "and I had a great respect and admiration for Harry Brown. So I said, 'Send him [Goldberg] along. We'll fit him in.'"

Goldberg began his career studying how marine plants and animals take up dissolved substances from seawater. "He wanted to know," Revelle remembers, "how diatoms, the tiny, one-celled grasses of the sea, assimilate phosphate and iron; how sharks accumulate iodine in their thyroid glands; and how tunicates, the most primitive animals with something like a backbone, accumulate vanadium."

Health of the Oceans. It was considered the definitive statement of its time on marine pollution. More important, perhaps, was the basic question Goldberg raised in its pages: *What is the ocean's capacity for absorbing human wastes?* In the book, Goldberg also set up the framework for the Mussel Watch program, which he began to implement in 1975.

Sponsored by the U.S. Environmental Protection Agency, scientists from five universities periodically analyzed filter-feeding molluscs from more than 100 stations along the U.S. coasts, generating a wealth of valuable data. The program is now international, having been implemented in China, India, Russia, and many developing countries.

Roger Revelle, looking for talent and short of chemists, said: "Send him [Goldberg] along, we'll fit him in."

In 1968, Goldberg co-authored a paper in *Science* on how winds were carrying large amounts of DDT and other pesticides from their land source into the sea. The *Science* paper was a personal landmark. It was the first in which Goldberg dealt specifically with ocean pollution, a field to which he has primarily dedicated himself for the last quarter century.

It has been environmental science that accounts for most of the awards heaped on his shoulders—for example, the coveted Tyler Prize, the first Bostwick H. Ketchum award from WHOI, even a carved garibaldi—California's official fish—from the Oceans Foundation of San Diego for developing an innovative program called the "Mussel Watch" (see *Oceanus* Vol. 26, No. 2, page 18). Revelle facetiously calls the garibaldi a "stuffed goldfish" because of its color.

In 1976, UNESCO published *The*

In the early 1980s, Goldberg heard disturbing reports about a major die-off in an oyster fishery in a French harbor. Checking the reports, he learned that there was a pleasure-boat marina in the same harbor, not far from the stricken oysters.

In California, there also were reports of similar deformities and die-offs of some marine organisms and, as in the case of the French harbor, they had occurred near marinas. Was there a common denominator in the incidents?

To find out, Goldberg sampled the water in more than 60 California harbors, each of which included at least one small-craft marina, and identified the source of trouble. It was tributyltin (TBT, see *Oceanus* Vol. 30, No. 3, page 69), a highly toxic chemical that was being added to most antifouling paints to protect the bottoms of both pleasure craft and commercial vessels.

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the carbon dioxide system in the ocean. His work on carbon dioxide focused on developing an understanding of how physical, chemical, and biological processes affect carbon dioxide concentrations.

Park also spent a lot of time in the laboratory. Along with his graduate students, he developed and tested seagoing analytical equipment, determined effects of carbon dioxide on the conductivity of seawater, and improved methods for the analytical chemistry of seawater, especially in the areas of gas analysis, alkalinity measurement, and nutrient determinations.

Park's scientific publication record is admirable and diverse. He has more than 50 papers in peer-reviewed journals, along with numerous reports, reviews, and communications, and many chapters in books. He also is well represented in foreign literature, having published papers in Japanese, Korean, Spanish, and French. His publications have dealt with wide ranging topics, such as marine pollution, marine environmental management, global conditions and change, and international coordination of marine science.

The Bureaucrat

In 1969, Park arrived in Washington to become a program director in physical oceanography for the National Science Foundation (NSF). In 1970, he became head of the Oceanography Section at NSF.

In 1976, he joined the National Oceanic and Atmospheric Administration (NOAA) as an oceanographer for the Outer Continental Shelf Environmental Assessment Program. Between 1977 and 1983, he was Manager of the NOAA Ocean Dumping Program.

Kilho was the right person in the right place at the right time in the mid-1970s when the United States, through NOAA, launched the development of a comprehensive program in ocean-dumping research. As a chemical oceanographer with many years of seagoing experience on several international expeditions, he brought a unique ability to apply science and people to the scientific issues of ocean dumping.

His approach was simple. Find the most talented people and give them an opportunity to apply their knowledge to ocean dumping. Accordingly, many academicians and governmental scientists who had not considered marine pollution or ocean dumping as a research area, moved swiftly to think about the problems and to develop fundamental questions that could be answered by the scientific method.

Park did not like the longer bureaucratic way of doing things. He believed in honor among his peers until proven otherwise, and in getting on with the job at hand. Park not only did not have any hidden agendas but he told everyone what he wanted to do and why, which is unheard of among those who have "Potomac fever."

Building on his research program management experience at NSF, he wanted to build a world-class research program in NOAA for ocean dumping and marine pollution research. Kilho even paid for his own travel when his travel budget was empty.

Once he was asked to meet with people from the Office of Management and Budget (OMB) and discuss why he needed so many millions of dollars for research. At the meeting, Park convinced OMB to give his program another million dollars. However, not all of NOAA's programs supported Park's efforts because many in the ranks felt that pollution was too applied a problem to be considered for basic research funds.

The results of Park's approach to the management of ocean dumping research provided U.S. scientists, resource managers, policymakers, and regulators with a wealth of information that could be used to guide policy. And they also touched in a very significant way the global community of scientists involved

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On the subject of ocean dumping, Goldberg fidgets when he hears the now-familiar (but, he claims, not scientifically based) complaint that the oceans are in deep trouble and they shouldn't be used to accept man's wastes in any way, shape, or form. Not so, Goldberg grumbles, and for at least a couple of decades, he hasn't hesitated to speak out or write about the subject.

"There are both 'sacred' and 'profane' views of the so-called 'virginity of the oceans,'" he says with a mischievous twinkle in his eye. "My views belong in the latter category."

In certain cases, he says, "controlled discharge to the oceans may provide a more reasonable disposal option than land. The trouble is that during the last two decades, environmental groups, through effective politics and communication, have, for all practical purposes, foreclosed that option."

He quickly adds that not just anything should be dumped into the ocean. Plastic waste and some toxic materials have no place at sea, he says. But certain industrial wastes, sewage, and even some hazardous materials such as low-level nuclear waste may well belong at the bottom of the ocean, in Goldberg's view.

Of course, Goldberg also adds, no ocean discharge should be undertaken without thorough scientific input to first determine the "endpoints" of any given area considered for discharge. An endpoint, he explains, "is the concentration [of a substance] beyond which the pollutant produces an undesirable effect."

Ed Goldberg isn't afraid to lay it on the line, even though his opinions may run counter to the mainstream. Commenting on this trait last year at a seminar honoring Goldberg after he received the Tyler Prize, a former graduate student remarked that Goldberg reminded him of a giraffe.

As eyebrows arched around the room, Roy Carpenter quickly explained: "Ed always said to his students, 'Don't be afraid to stick your neck out with an unpopular idea if you know you're right.' It was good advice. He's been taking it himself for years."

Now nearing age 70, Goldberg shows no signs of slowing down, nor have the years dimmed his capacity for sticking that figurative, giraffe-like neck into controversy. Some colleagues suggest that Goldberg looks for a good fight and that, like a fish battling up current, his single-minded, often combative stance is an ingrained part of his nature.

"There are both 'sacred' and 'profane' views of the so-called 'virginity of the oceans,' " Goldberg says. "My views belong in the latter category."

"I suppose that not being afraid to say something unpopular is what keeps my juices flowing," Goldberg responds. "I enjoy a good argument, and I refuse to be quiet just because it seems the thing to do."

To escape work pressures, Goldberg watches movies, reads books, putters in a garden at his home in Encinitas, just north of Scripps, and—a major passion in his life—he travels.

"I go to a movie theater at least twice a week," he says, "usually alone. That way, I don't have to argue with anyone—even my wife—about whether the film was good or not." Occasionally, he takes one of his two teenage children (two others are grown and "out of the nest" as he puts it).

(continued on page 84)

in marine pollution research and marine pollution processes.

Park took full advantage of the fact that ocean dumping was a global issue when he organized the International Ocean Disposal Series so that scientists, regulators, and policymakers, at home and abroad, could gather together on a periodic basis. At these meetings they exchange research results and information on ocean dumping, enhance the scientific consideration of waste disposal, and generate recommendations and guidelines for future ocean disposal research.

In government, one is supposed to follow the directed path, not create it. Kilho is an exception.

The Statesman

From 1984 to 1987, Park was the Senior Advisor to the U.S. & China and the U.S. & Japan programs. His ability to read Chinese was valuable during negotiations between the U.S. Marine Pollution Delegation and China's National Bureau of Oceanography (NBO, now renamed SOA for State Oceanic Administration).

In the late-1980s, he caught "UN fever," and served as Deputy Director of the Programme Activity Centre for Oceans and Coastal Areas of the United Nation's Environment Programme, in Nairobi, Kenya.

The Father

If you ask Park about his greatest accomplishments, he will refer to his two sons and their mother—the "Maiden of Grace" Sue Park—pointing with great pride to their accomplishments and the fact they did it by themselves. Both boys were National Merit finalists, and went to the University of California, Berkeley, for undergraduate education. The older, Arvin, is an assistant professor at the University of California, Davis, in computer science with a Ph.D. from Princeton. The second son, Robert, has an M.D. in internal medicine from the University of California, San Diego. Kilho is married to Sharon A. MacLean, a fisheries researcher for NOAA's National Marine Fisheries Service in Narragansett, Rhode Island.

The Visionary

Park has always been a determined individual. He created an international symposium series on the subject of wastes in the ocean, which since 1978 has met every 18 months with a rigorous publication schedule—one volume published by Plenum Press, six volumes by Wiley-Interscience, and six volumes by the Krieger Publishing, and two special issues of the *Marine Pollution Bulletin*.

The Eighth International Ocean Disposal Symposium was held in Dubrovnik, Yugoslavia, this last year, and these papers are scheduled for publication in a major journal. At first, these symposia were a forum to bring together the researchers working with NOAA to study physical, chemical, and biological processes connected with the disposal of wastes in the sea.

As others heard of the meetings, the symposia grew until they became one of the top marine pollution meetings. These meetings were really Kilho's way of peer review in which the high level of discussion elevated the level of research higher and higher. To these symposia, Park invited the leaders in each field from all over the world to come and give review lectures.

The NOAA Ocean Dumping Research Program was phased out in the mid-1980s because ocean dumping of municipal and industrial wastes was phased out by Congress so there was nothing left to study. Deep-ocean dumping of sewage sludge did not begin until 1986 and has been studied within NOAA ever since.

(continued on page 85)

"I read to escape, too. I like Dickens, Mark Twain, and a few modern authors. I recently finished a book on the history of the Jews. It doesn't matter what the books are, as long as they are distinct from the subjects of my work."

Goldberg's travel schedule is a hectic one, but he revels in it. "Oceanographers have a really beautiful pedestal on which to enjoy the good life," he explains, "and that is travel. Travel is a narcotic and I can't get enough of it." He especially enjoys visiting developing and unspoiled places before they become too popular—Easter Island, for example.

What's next for the busy, feisty Goldberg? "Right now I'm writing another book. Like *The Health of the Oceans*, it will be published by UNESCO. Its theme is how man will ultimately utilize ocean space in the future as he has with land space in the past."

There will undoubtedly be a lot of conflict in using ocean space, but the potential is there, Goldberg feels. In the book, he lists four main uses—waste disposal, mariculture, recreation, and transportation. "The ocean is a fascinating place," he says, "and I'm having a lot of fun writing the book."

Joseph E. Brown is a free lance writer living in Rockport, Maine. He is a former editor of Oceans *magazine, the author of 14 books, and writes frequently on marine science.*

The Poet

Kilho is a self-taught poet and pianist. He developed these talents to improve his sensitivity and ability to express himself. His great enthusiasm for work springs from life itself. His poet pen name is Momiji, which means "Japanese Maple" in Japanese.

NEW YEAR'S POEM

Galloping December Horse's Symphony
goes on
Soon to enter its final movement
Mastering all the energy left and wisdom
For the final crescendo yet to come.

My first score years have been
A time of assimilation of three cultures.
I then became a trilingual survivor
Enjoying the orderliness of mathematics
and music.

My second score years have been
A total dedication to marine science
Working, working, working, full speed
ahead
Finally reaching a plateau at forty.

My third score years have been
The time to expand horizon as a human
Slowly, quietly and gently coming down;
Simplifying, selecting, nurturing,
writing.

My fourth score years shall be
The most melodious period of life
To see, feel, enjoy the beauty of being
human
Pacing steadfastly for the final crescendo.

—Momiji
Yawgoo Valley, Rhode Island
1 January 1990

My lunar calendar birthday is two days after the December full moon in the Year of the Horse. So, I am a December Horse. This Lunar New Year is the Year of the Horse, according to the Chinese zodiac.

The Friend

Once you become a friend to Park, he nurtures that friendship through all. Do not let someone sacrifice one of his friends because you now have two bodies to deal with. There are many levels of friendship with Kilho, and one does not move between levels. He refers to himself as 50 percent S.O.B. and 50 percent nice guy, but this is like having one foot in ice water and one foot in boiling water, and on the average being OK.

The Dreamer

Park sees the forest although he may not see each tree. He is more of a French impressionist than a biological illustrator. His inner goals are to be a facilitator and motivator, with a need to see the good side of people. He strives for "simple understanding" of complex issues.

He is fascinated with President Kennedy's idea: "A time for being human." His view of the 20th century is a vision split between military and economic wars. The 21st century offers "survival wars for mankind as a species"—and the opportunity to establish some balance between the plants and the animals. He sees this as a period to preserve 10 trees for every 1 human being.

Paul Kilho Park marches to a drum that only a few hear or understand. He never asks what something costs or why we should not do it, but how. His thinking and logic are sometimes three to six moves ahead (as in a game of chess). Thus, in the day-to-day mode, one cannot often discern where he is coming from or going to.

Michael Champ, an ocean scientist, is President of Environmental Systems Development, Inc., in Falls Church, Virginia.

'BOY, YOU HAD ME WORRIED FOR A MOMENT THERE—I THOUGHT YOU SAID THREE TO FIVE YEARS!'

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WASTES AND THE OCEAN

In the evolution of our civilization
Civitas *(city) is formed where*
Invention and industry blossom
Through cross-fertilization of minds.
There, some men and women are set aside
To produce science and philosophy,
To flower our art and literature.

In civitas, *water is the medium of life,*
For drinking, transportation, communication
And for the safe disposal of our wastes.
We must continue our civil orderliness
Through which wastes are disposed safely.

The ocean, too, is used for waste disposal
As the land and the atmosphere are used
To bury, decompose, or disperse wastes.
Let us be analytical and synthetical on this
To harmonize our civilization with the environ
So that our children see our wisdom,
Not inherit our wastes.

—Momiji
Terre Mariae
9 March 1982

LETTERS

To the Editor:

I just read the letter from Victor Scheffer and your reply in Volume 31, Number 4. A little more needs to be said about the estimate of minke whale populations.

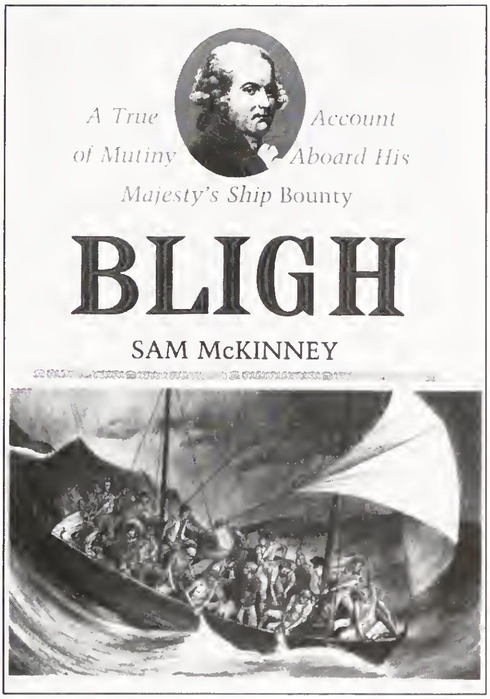
The present number, 600,000 in the Southern Hemisphere, comes from properly conducted sightings surveys, carried out during six years. The confidence limits on this estimate—the best we have for any whale population—are plus-or-minus 50 percent. This number is probably about 30 percent less than when exploitation of this species began in 1972.

There are no valid estimates yet for minke whales in the Northern Hemisphere, though one might become available for the North Atlantic later this year. All previously quoted figures, including the 125,000 you cite, have been discredited because they were obtained by seriously flawed indirect methods.

How does such confusion arise? Primarily because the International Whaling Commission (IWC) Secretariat has gotten into the habit of publicly distributing a table of numbers. This table has not been updated for many years, so the figures it contains are seriously at variance with the recent work of the IWC's own Scientific Committee—of which I have been a member since 1959. As a result of my protestations to the committee in June, 1989, a promise was extracted that this misleading table would no longer be made available to enquirers. Nevertheless, the damage has been done; the erroneous figures have been published in several recent books and articles and are bound to be taken by their readers as authoritative.

A new table is being put together by a few Scientific Committee members, including myself, based strictly on the committee's work, but to avoid political interference it will not be published by the IWC.

Sidney Holt
Città della Pieve, Italy



Bligh: The True Account of the Mutiny Aboard His Majesty's Ship Bounty **by Sam McKinney. 1989. International Marine Publishing, Camden, ME. 196 pp. $22.95.**

Sam McKinney's book on Captain Bligh and the *Bounty* is unusual. In a writing style that is both eloquent and exciting, this is an authoritative and scholarly work that offers a radically new view of a romanticized and controversial incident in history.

Unlike other books on the *Bounty*, McKinney does not treat the mutiny in isolation. He

paints a colorful and accurate backdrop of Britain and the Royal Navy prior to the Napoleonic Wars. He tells of the peacetime navy's scientific mission to fulfill the thirst for knowledge of the scientifically inclined and much-maligned "mad" King George III.

McKinney gently points out very early that we have much to learn. He tells of James Cook, the finest of all British seamen-explorers. A captain famous for his gentle and considerate nature, Cook had high regard for Bligh who served as a 22-year-old sailing master on the *HMS Resolution*. From Bligh's practices aboard *Bounty*, it is obvious that he learned something from Cook's humanitarianism and concern for shipboard health.

We also learn that *Bounty* was not a stately ship-of-the-line, nor a dashing frigate, but a simple 91-foot, beamy, and somewhat ugly merchantman of 215 tons that previously had been called *Bethea*. She was much like many of the post-World War II oceanographic research ships: conversions that fulfilled missions way beyond the expectations and intentions of their original designers.

McKinney chronicles the inefficiencies of the naval system that Bligh had to overcome before *Bounty* could sail from England. There were delays in receiving orders from the Admiralty. These prevented him from reaching the Drake Passage and rounding Cape Horn during the optimum season for reaching the Pacific.

Most importantly, we read of how the traditional distance between master and crew on *Bounty* was diminished to a point where he was almost guaranteed to fail. Loyal marines who provided an essential physical barrier between master and crew did not embark on the *Bounty* for lack of berths. Bligh was denied the captain's isolation in the gallery cabin because it had become a greenhouse for breadfruit. (The ship was being sent to Tahiti to fetch these fruit for transport to Jamaica as experimental slave fodder.) Worse, and again due to a lack of berths, Bligh had to fulfill the dual function of master and purser. The purser was the lightning rod who assumed the blame for all inequity and insufficiency aboard Royal Navy ships.

While McKinney describes the "real" Bligh as a seaman of extraordinary capability who used the lash less than most Royal Navy captains, he also shows him as a man insecure in command. As anyone who has been to sea for extended periods knows, this insecurity corrodes slowly, inevitably, and cumulatively through any voyage. In Bligh, it was manifested by his volcanic temper and refusal to delegate. We also see the "real" Fletcher Christian as a man of little courage, easily used by others.

McKinney's faithful and exclusive adherence to original documentation is obvious to the reader. His principle sources were Bligh's log of *Bounty*'s voyage; the log of the *HMS Pandora*, written by the ruthless Captain Edwards whose lost ship sank on Australia's Barrier Reef with many of the captured mutineers still in chains; and the log of George Hamilton, *Pandora*'s surgeon. The final chapter is drawn from Captain Beechey's log of *HMS Blossom*, which in 1825 was the first Royal Navy ship to make contact with the last surviving mutineer, John Adams, and the descendants of the other mutineers on Pitcairn Island.

McKinney wisely discounts a further account written by John Fryer, the master of the *Bounty*, due to the man's incompetence and personal bitterness toward Bligh. McKinney's counterpoint to Bligh's log comes from the journal of James Morrison, *Bounty*'s extraordinarily articulate boatswain's mate who was one of the mutineers who stayed in Tahiti and was captured by *HMS Pandora*. Morrison was subsequently condemned to death by court-martial and then pardoned. One particularly fascinating passage deals with how the Christian family, who were influential lawyers, manipulated the press to dishonor Bligh and recast Fletcher as a noble victim.

For all its authenticity and attention to detail, McKinney's book is no less riveting. It is one of the finest and most exciting sea stories ever told by an extraordinarily articulate author. The book is in very clear type, making it easily readable. The afterword explains the fates of many of the players in the story, and the appendices provide useful background on the chronology and Royal Navy practices and regulations. If I were to find a fault with the book, it is with the book's artwork which smacks of the "Boy's Own"

style of illustration common in lighter textbooks and adventure stories published in the 1950s and earlier.

I read this book on a ship steaming from Tahiti to Pitcairn Island in November, 1989. I could think of no better preparation for visiting that extraordinary place than McKinney's *Bligh*.

—Paul Dudley Hart
Director
Industrial and International Programs
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

Biological Oceanography—An Early History, 1870–1960 **by Eric Mills. 1989. Cornell University Press, New York, NY. 378 pp. + xvii. $47.95.**

Biological Oceanography—An Early History, 1870–1960 is a narrative about life in the sea, a chronicle of ideas, and the story of the men and women who first studied the productivity of life in the waters of the North Atlantic Ocean. Mills relates how the initial study of plankton

distribution patterns led quite naturally to the investigation of the chemical, physiological, and ecological processes that explain the observed patterns of plant and animal life in the sea.

The account begins during the last quarter of the 19th century in Kiel, Germany, with the physiologist Victor Hensen. To him, phytoplankton was "this blood of the sea"—a metaphor conveying his view that the ocean was a superorganism that could be studied in an analytical, fully quantitative way, even as physiologists examine and understand the internal processes of other living organisms.

This concept was an extraordinary one, a marked departure from the phylogenetic speculation, descriptive biology, and biogeography that had prevailed until that time. It was Hensen's opinion that the emphasis was to be "replaced in practice and in thinking by attempts to link quantitatively the production of organisms to their chemical and physiological surroundings." The object was to be no less than "an estimate of marine production that would allow the abundance of fishes to be calculated or predicted"—a goal as elusive then as it remains today.

Mills describes the scientific questions, the milieu, and circumstances that led to the remarkable results of the "Kiel School"—Hensen, Karl Brandt, Hans Lohman, and others—from Hensen's days until its decline after 1912 and eventual end in the 1920s. "At various times Prussian imperialism, agricultural chemistry, microbiology, the problems of German universities, failure of the commercial fisheries, the development of analytical chemistry, the establishment of international scientific organizations, and sheer scientific curiosity played their roles" in determining the course of events. Mills concludes, "the decline and demise of the Kiel School . . . may be accounted for nearly entirely by institutional factors, particularly the inflexibility of the German academic system . . . [and] to the lack of career opportunities," rather than the "exhaustion of ideas." Mills convincingly shows that during its relatively short life, the Kiel School produced the basis from which ultimately stems almost all present understanding of the cycle of plankton productivity in the ocean.

The narrative moves from Kiel to Plymouth, England, and to the work of E. J. Allen, W. R. G. Atkins, H. W. Harvey, L. H. N. Cooper, Sheina Marshall, A. P. Orr and Marie V. Lebour. Except for the latter three, they were trained primarily as inorganic chemists. The research of this talented group, precariously financed mainly by government grants, was to directly influence research in America, largely through their contributions published in the *Journal of the Marine Biological Association, U.K.*

At Woods Hole, Massachusetts, in the mid-1950s, Alfred C. Redfield, Bostwick Ketchum, and John Ryther were in various ways markedly influenced by the Plymouth investigations, and Harvey's volume, *The Chemistry and Fertility of Seawaters*, appeared on almost every biologist's bookshelf. But it was one of G. Evelyn Hutchinson's students at Yale, Gordon Riley, who most prominently provided the link between Plymouth and Woods Hole and the next step in the study of productivity of the ocean.

Riley's mathematical and analytical approach was regarded at the time by many ecologists as arcane and largely inscrutable. It started with multiple correlations, but when these failed, led to a collaboration with Henry Stommel, then a young, newly employed physical oceanographer at the Woods Hole Oceanographic Institution. Riley also used the *Atlantis*, then the principal seagoing vessel at Woods Hole, to collect data to use in his models. With the help of Stommel, Riley included for the first time the role of vertical eddy diffusion on the distribution of nutrients as well as the phytoplankton itself. Along with such physical considerations they incorporated quantitative measurements of grazing by zooplankton, following the original work of Marshall and Orr.

At this point, history begins to overlap with the near present; indeed, some of the principals are still living in retirement at Woods Hole or elsewhere. This book does more than just record discoveries as they occurred: it deals in considerable detail with the biological concepts involved, and there are many. It also demonstrates once more that because knowledge—and science in particular—is empowering, it necessarily must be

political. This has always been so, not only in the 19th and 20th centuries, but as far back in history as one cares to delve.

In a sense, Mills's book is idiosyncratic in dealing only with plankton productivity, all the more remarkable as his own early research dealt largely with the systematics of deep-sea amphipods. He has justified this omission by observing that "deep-sea biology [of the benthos], which flourished before the turn of the century, became a side issue (if it were carried on at all), a specialized, difficult, and even scientifically uninteresting residuum of 19th century thought."

But times have changed and it was precisely in the early 1960s that the deep-sea benthos again gained prominence. Meanwhile, the reader will find nothing in this volume about the resurgence of deep-sea biology that had begun in the 1940s and '50s with the Swedish deep-sea and *Galathea* Expeditions.

To the historian this book will be interesting because it brings into focus bureaucracy and politics and their effects on marine science; to the biologist it brings an understanding of the origin of ideas. Eric Mills has written a scholarly work that is fun to read. That surely is an accomplishment!

—Rudolf S. Scheltema
Senior Scientist, Biology Department
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

BOOKS RECEIVED

BIOLOGY

Aquatic Oligochaete Biology IV edited by J. L. Kaster. 1989. Kluwer Academic Publishers, Norwell, MA. 252 pp. $125.00.

The Bottlenose Dolphin by Stephen Leatherwood and Randall R. Reeves. 1990. Academic Press, San Diego, CA. 653 pp. $90.00.

The Natural History of Seals by W. Nigel Bonner. 1990. Facts On File, New York, NY. 196 pp. + xvi. $24.95.

Pacific Coast Inshore Fishes, Third Edition by Daniel W. Gotshall. 1989. Sea Challengers, Monterey, CA. 97 pp. $18.95.

Voyaging to the Whales by Hal Whitehead. 1989. Stoddart Publishing, Toronto, Canada. 195 pp. + xii. $28.95.

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The Complete Guide to Environmental Careers by Lee P. DeAngelis, Stephen C. Basler, and Loren E. Yeager. 1989. Island Press, Covelo, CA. 328 pp. + xvi. $14.95.

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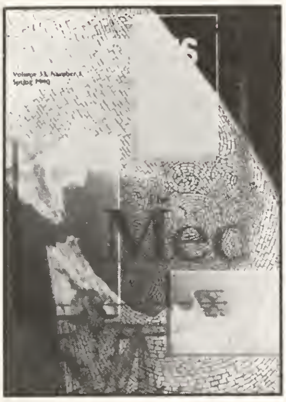

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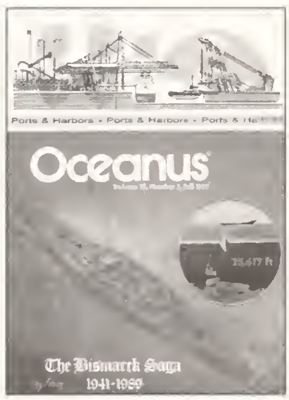

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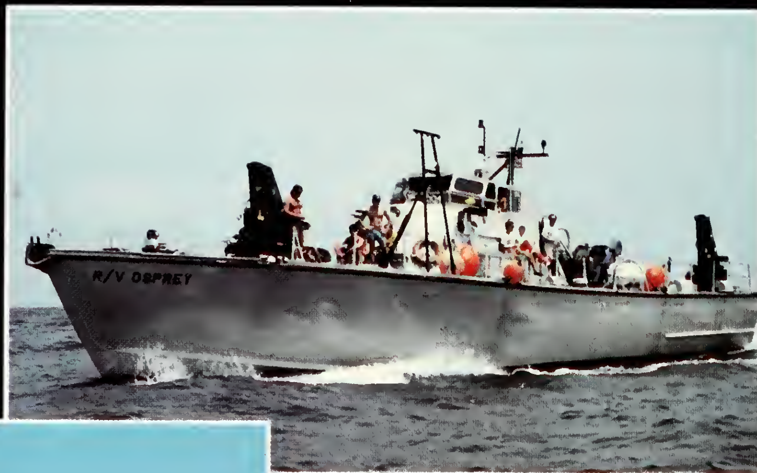

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